Interplanetary Soc.

Journal

of the

British Interplanetary Society

Volume 13

1954

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Published by
The British Interplanetary Society Limited
London

The BRITISH INTERPLANETARY SOCIETY

LIMITED (by Guarantee)

Secretarial Address: 12, Bessborough Gardens, London, S.W.1.
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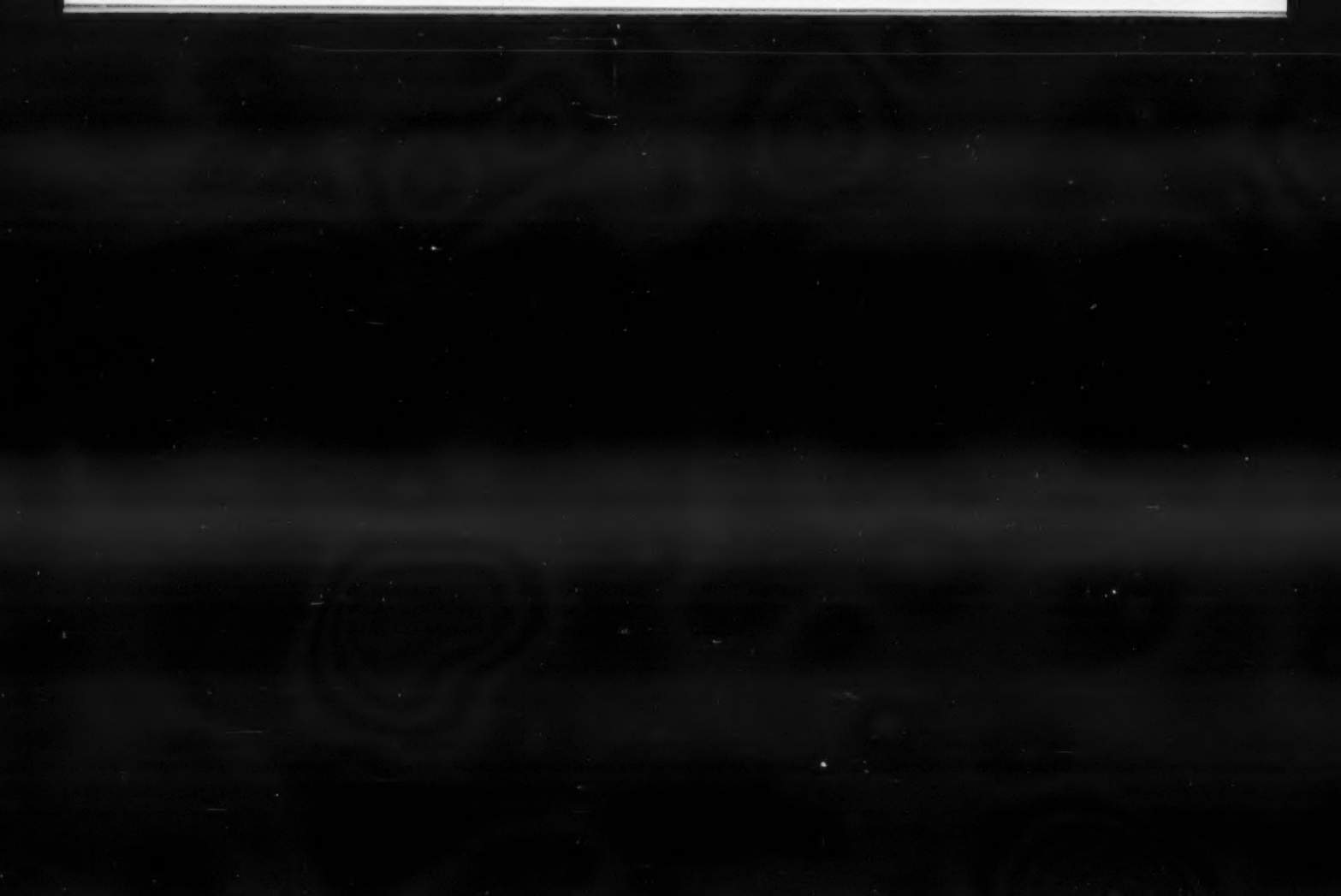

Journal
of the
British Interplanetary Society
Edited by L. J. CARTER, A.C.I.S.
Vol. 13, No. 1 LVI January, 1954

A PROGRAMME FOR ACHIEVING INTERPLANETARY FLIGHT

BY A. V. CLEAVER, F.R.Ae.S.

(*A paper read to the British Interplanetary Society in London on October 3, 1953.*)

SUMMARY

The various phases of research and development which must be traversed before interplanetary flight can be achieved are discussed. Phase I is considered as extending to the establishment of unmanned satellite rockets, orbiting the Earth with telemetering equipment and automatic instruments; Phase II will cover the building of manned satellite rockets, perhaps with the circumnavigation of the Moon by special vehicles, while Phase III will consist of true interplanetary flight, with landings by human crews on other planetary surfaces, and their safe return. The aspects of finance, utility, motivation, and outstanding technical problems are discussed. It is considered that military sponsorship will almost certainly ensure the achievement of Phase I and probably that of Phase II also, both of which could be possible with extrapolation of present chemical rocket technology. Phase III, however, will probably require the application of new principles, such as the use of nuclear power, and also the growth of sufficient public support to justify embarking on the project. It is suggested that the interplanetary societies, through their international federation, might be primarily responsible for fostering such support, and perhaps also for administering this concluding phase of the programme.

Introduction

I feel that I may fairly plead two different, but probably not unconnected, excuses for returning to the theme of an earlier paper.[1] In the first place, I was asked to do so by the B.I.S. Council. Secondly, there is (I think) a growing realization, not merely on my part, that the biggest problems of all in interplanetary flight are likely to be political rather than technical. (The term "political" is here used, of course, in its broadest possible sense, as embracing all economic, social and ethical questions.)

It seems desirable to emphasize at the outset that the views expressed are entirely my own, and not necessarily shared by the British Interplanetary Society, or anyone else. For this reason, a personal approach and phraseology has been employed throughout. Those wishing to consult alternative sources of opinion, on various aspects of the subject, should find references 2–14 useful; the papers [14] presented at the 1953 Zurich Congress are particularly relevant. It should perhaps be explained that this present survey was commissioned before it was known that they were to be read, and was completed before they were available for study.

All the statements made in this paper as regards costs and time scales are, of course, inevitably highly conjectural. In so far as they can be justified, some

supporting evidence is collected in Appendices A and B. It is in connection with the interpretation of such data that any paper like the present one becomes so essentially a matter of personal opinion, as I have already emphasized. The past experience of the actual writer will, in any individual case, have given him a sense of atmosphere, of what can best be described as "feel." His conclusions will be greatly influenced by the balance of pessimism or optimism, caution or rashness, enthusiasm or stolidity, in his character—and (to an even larger extent) by the general nature of his background. Thus, technical workers in electronics, atomic energy or aeronautics might well tend to be more sanguine about the prospects for space-flight than those specializing in older fields of science and technology which have no recent tradition of rapid change, great effort and lavish expenditure. In effect, this almost amounts to saying that workers in fields enjoying a large (perhaps even a predominant) military application are more accustomed to take these things for granted. They tend to assume that in practice the trends with which they are familiar are bound to be extrapolated without interruption into the new subject of astronautics. While this may indeed happen, the inevitability of the process is far from certain and is at least worthy of critical examination.

Technical Considerations

The technical difficulties which still bar the way to space flight, and especially to true interplanetary travel, are immense. There is certainly no desire to gloss over them in this paper, but rather, most definitely, the reverse. Although it is not my present purpose to deal with them in any detail, much of the discussion which follows should serve to emphasize the magnitude of the problems involved and the time and effort which will be needed for their solution.

Nevertheless, it is my conviction, shared with other astronautical enthusiasts, that all these obstacles *can* be overcome, and that all the essential basic knowledge needed to build true interplanetary vehicles *could*, in all probability, exist by about the turn of the present century. To express such opinions is not necessarily, as some of our critics still seem to think, at all the same thing as to dismiss the difficulties lightly. Rather, it can be (and in my own case, of course, I like to believe that it is!) based on an intelligent and informed appraisal of those problems, and on a broad appreciation of all the trends and potentialities of modern pure and applied science.

However, neither is the statement that a thing is possible the same as saying that it will happen. If we believe (as I certainly do) that spaceships *could* be built within the next few generations, albeit at the great expense of overcoming immense technical difficulties, then the question of whether they *will* be built at that time depends entirely on such non-technical considerations as motives and availability of resources.

It was for this reason the earlier statement was made that the greatest astronautical problems were political rather than technical. Paradoxically, the magnitude of the technical problems serves to emphasize the truth of this proposition, rather than otherwise, simply because the effort to overcome them will need to be correspondingly greater.

Earlier technological innovations, even some which later developed great

supporting industries, and found applications that exerted an almost universal influence, were able to grow from quite modest origins. The automobile and the aeroplane are perhaps the most striking examples; the first cars and planes were small, cheap and simple (not to say crude) machines, which were capable of being built by amateur experimenters, having only very slender resources, even at their own expense. They were, in fact, almost invariably produced in just exactly this way, and only later, after demonstrating at least a qualified practical success, did they receive any considerable backing from large commercial or government sources. Almost as soon as the basic technical knowledge existed to build motor-cars and aircraft, they *were* built, even without there having been much public demand for their production, or any powerful backing for it. Once they existed, appreciation of their practical uses followed rapidly and soon brought with it both the demand and the backing. However, even had these things never materialized—if the machines concerned had been entirely useless and their development undeserving of any support from society and its official organizations—it is nevertheless certain, on a simple statistical basis, that at least some prototype automobiles and aircraft would have been built. Moreover, this would have happened almost as soon as they were in fact built. The random whims and intense personal interests of a few private inventors and sportsmen, adventurous or eccentric in outlook, would have ensured this.

In passing, it is interesting to note that some of the greatest aviation pioneers had little faith in the extent of ultimate usefulness of the vehicles to which they showed such devotion. Octave Chanute, in the first decade of this century, wrote:—

"The question occurs as to what is to be the probable use to man of these new modes of transit. We can already answer that they will have no commercial value for the regular transportation of freight or passengers, as the useful loads will be too small and the trips too uncertain and irregular. We may, however, discuss their merits for sport and for war purposes, and leave it to the future to show whether new utilities are to be found beyond those of explorations of otherwise inaccessible regions. . . . Apparently the chief use for flying machines will be in sport. Their advantages will be their cheapness, as the cost need not exceed 5,000 dollars; also the superiority of their speed, which is now 40 m.p.h. and presently will be increased to 50 m.p.h. or more. Moreover, they are small and cheaply housed. Their disadvantages are that their useful loads will always be small, as their own weight increases faster than their total carrying capacity."

Nevertheless, the main interest of Chanute's life, and one on which he expended what, by the standards of a hobby, must be accounted considerable amounts of time and money, was experimentation on heavier-than-air flying machines. It will always be possible to find individuals, as opposed to large organisations, of such quixotic character.

A further lesson to be learnt from the many inaccurate predictions of the preceding quotation concerns the obvious occupational risk run by any prophet. . . . While being uncomfortably aware of this, I will nevertheless attempt to play the role, and forecast the astronautical future.

One thing at least is certain: a couple of generations of further scientific

progress have brought mankind to a very different state of affairs from the one existing at the dawn of practical aviation. Technical knowledge has increased to such an extent that most new devices applying it are now of immeasurably greater complexity and cost. Only the very preliminary work on their development is undertaken, on a "private venture" basis, by individuals or industrial and commercial interests; state backing is required from quite an early stage, often from the very beginning. Radar, advanced jet aircraft, guided missiles, and any applications of nuclear energy, come into this category; the latter represents the most extreme example to date. It cost some £500,000,000 to set up the organization which produced the first atomic bombs. There would never have been any big practical applications of the laboratory discoveries in nuclear physics if it had been necessary to leave their development to private or amateur interests; some motive, which society regarded as an urgent necessity, was required to ensure that adequate resources were made available by several governments. The consideration which actually led to effective practical action was the one which our times seem to regard as the most urgent of all: the demand for more powerful weapons. The peaceful uses of nuclear power would certainly have provided another adequate justification for large-scale effort, though at a later date and on a much reduced tempo. However, the wishes and ambitions of a relatively few individuals would never have sufficed and they would have been powerless to achieve anything on a practical scale by themselves, because of the quite fundamental technical reasons which dictate the politics of the issue.

Interplanetary flight will be another vast technical enterprise of which this will be true, and it is therefore very relevant for us to discuss the questions of available and required resources, and of motivation, with which this paper is primarily concerned. We can then proceed to consider what sort of organization would be needed to handle the Interplanetary Project, who might one day be persuaded to set it up, and how all this might be done.

Available Resources

I have occasionally heard it suggested that the world could never afford interplanetary flight under any circumstances, and it might first be as well to dispose briefly of this most depressing opinion of all. Although I find that I tend to take a more pessimistic view of the cost and effort involved than many of my fellow astronautical enthusiasts, I do not think the situation is as bad as all that.

Very large financial figures, like astronomical distances, are inclined to numb the mind into such an awe-struck state that they become meaningless. However, for what it is worth, the total cost (to both sides) of World War II has been estimated by *Life* as roughly £1,500,000,000,000, while in 1950, Sir Richard Fairey estimated[16] that a total of nearly £100,000,000,000 had been spent on aviation, throughout the world, since the Wright Bros. first flew in 1903. He thought the current rate of annual expenditure was about £4,000,000,000; of this, well over 10 per cent. would probably be accounted for by research and development. These rates were several times greater during the war, and today have undoubtedly increased again beyond their 1950 level.

Other interesting figures are represented by the published annual national budgets of the major world powers, which are approximately as follows:—

	Total	*Military*	
U.S.A. ..	28,000	16,500	£ millions
U.S.S.R. ..	50,000	10,000	
U.K. ..	5,000	1,500	

£1 = 2·80 dollars = 11·2 roubles (official rates).

It has been said that Britain has spent over £100,000,000 on atomic research since the war, while the United States is currently spending at a rate of nearly £1,000,000,000 *per year* on all aspects of atomic energy, together with several further hundreds of millions on guided missiles.

Later in this paper, and in its Appendix *B*, other relevant figures are quoted and also some for the probable cost of various phases of the Interplanetary Project. As regard the latter, it will be sufficient here merely to state the *order* of the sums involved. No single project during any phase of the undertaking (even the final ones) is likely to cost much more than £1,000,000,000, to be spent at a rate greatly exceeding £100,000,000 per year.

Even these immense sums are therefore seen to be well within the resources of mankind, especially when it is remembered that these resources are themselves capable of vast expansion. The population, and hence the work-potential, of the Earth is increasing; with saner administration, leading to better international relations, and much wider application of scientific methods to food production (among other things), even this increased population could be healthier and better fed, with beneficial effects on its productive capacity. Improvements in manufacturing methods, such as greater mechanization, can also greatly increase the useful output per man-hour of work. The world of the future will thus be potentially capable of a very much greater scale of activity than the world of today.

Of course, once again it does not follow that these things will happen, simply because they could be made to happen, but the fact remains that the possibility exists, and it is with ultimate possibilities that we are concerned. If at least some progress is not made in these directions, then perhaps the problem of space-flight may remain an academic one until some much later stage in the world's history, for the social tensions of man, coupled with his increasing technical powers, have provided all the explosive ingredients of a situation which no culture capable of achieving space-flight might survive.

A series of continuing destructive wars might prevent the achievement of interplanetary flight within the relatively near future, but the lack of adequate resources certainly need not. If man chooses to do so, then he can afford to cross the interplanetary spaces within the next few generations, especially if one of two developments takes place:—either, if he sees some reason to devote a part of his present military budget to space-flight, even if still for military reasons, or—better still—if he greatly reduces his wasteful expenditure on military matters and diverts some part of the saving to astronautics.

Motives

We have seen that already many of the more advanced technical developments of today are proceeded with only, or at least primarily, because of their military importance. This is especially true in their early phases; subsequently, alternative applications emerge as a sort of by-product, and receive substantial support in their own right. Civil aviation is perhaps the most striking case in point, but even medicine can show examples which are similar in principle. Many surgical techniques, "miracle drugs," and large-scale measures for prevention of disease (involving more effective insecticides, etc.) owe their origins to basically military needs.

A great many people would still regard any large expenditure on astronautics as a complete waste, and a spaceship as being totally useless; this is true even of some who would be quite prepared to acknowledge the ultimate technical feasibility of proposals for space flight. At a guess, I would say that perhaps the majority of the world's present population falls into this category, and would therefore suggest that there is good reason, at this point in our discussion, for some Joadian consideration along the lines of "It-depends-what-you-mean-by *'use'*."

What *do* we mean by *'use'*? Something that contributes to the health or wealth of mankind, makes us live longer in greater physical comfort, gives us more leisure and better food and drink? It would admittedly be difficult to make out a case for space-flight along any of these lines—but, on a similar basis, it would also be impossible to justify a lot of the present activities of mankind. In particular, it would be impossible to justify the one on which we have so far expended most of our efforts during this twentieth century.

It is hard to think of anything which could be much more utterly "useless" than a bomber, a submarine, a tank, a guided missile or a gun, on the basis of any standard of value to the individual which has been mentioned so far. And yet, almost every man in our twentieth-century street unquestioningly accepts the fact that some of the resources of his community should be expended on these things as being quite right and proper. He has currently been persuaded that something approaching half his potential wealth should be poured out in this direction, and—while such lavish military budgets are undoubtedly beginning to be responsible for some protests—even this state of affairs is tolerated in the leading nations of today.

The reason, of course, is that along with health and wealth another need of mankind is a certain measure of security, both for the individual and for the community or nation. In the world as it exists today, this requirement provides a "use" for armaments, since they are believed to consitute a defence and a deterrent against aggression. With the reservation that I earnestly hope our statesmen will be capable of providing an alternative more effective and more civilized method of solving or avoiding international disputes within the next few generations, I am as prepared as anyone could reasonably be to accept the need for air forces, navies and armies, in the meantime. It is the dilemma of our age that our knowledge of how to handle human, and (in particular) international, relations has not kept pace with our ability to handle the physical forces of

nature. We must learn how to rectify this situation if we are to survive, and there is probably not much time left for us to do it.

The years in question, however, are roughly coincident with the period of our first opportunity, as a species, to enter upon the exploration of space. This result, a consequence of the fact that the advance of science has made both situations possible, has led certain opportunistic spirits to enquire whether it cannot be turned to the advantage of astronautics. Openly or otherwise, the question has, in effect, been asked: cannot the achievement of space-flight be shown to have a bearing on considerations of national defence and security, so that the latter provide a motive for the former? Those who have most often asked this question have usually answered it themselves with a resounding affirmative, in which, in all probability, they have been only half-sincere at best. This is not to say they have been completely insincere; I doubt whether complex questions of human conduct are often subject to such simple, single, descriptive explanations. That is to say, the individuals concerned do believe in the military applications of space-flight, and therefore that they have provided the world with a valid motive for achieving it, but they themselves need no such motive. For them it is a contributory incentive, large or small in proportion to others which we shall discuss later. If they do not realize this, they have probably been guilty of rationalizing their own sub-conscious desires—a not unusual human failing.

In other astronautical circles, any acceptance of the military application of space-flight has, on occasion, been regarded as far from respectable, even downright immoral. If that is to be the motive for achieving interplanetary travel, on this view, we had better not have it at all. I might feel greater sympathy for this shade of opinion if it were likely to remain the *only* motive, for all time, but that is definitely not so. In any event, it would hardly be logical to agree with the case for building jet bombers, atomic bombs and guided missiles—as I have done, on grounds of present expediency—and then draw the line at space vehicles. If these began as military devices and then developed other purposes of greater ethical or cultural value, then (on the analogy of civil aviation, for example) I do not think we should forego the final results on account of their origin, without some very good and special reasons. I personally do not believe these exist; there is no *special* reason why a spaceship should be a particularly hateful weapon. Like the atomic bomb, it would be a very expensive one, and again, it *might* be another very powerful one, but these characteristics in the long run are likely to lead to the very desirable result of war eventually ceasing to be practical as a means of settling international disputes. On a strictly moral plane, there is no distinction to be drawn between killing by guided bomb or bow and arrow, fired from a rocket vehicle or a war canoe.

Whether we like it or not, I think that the early stages of astronautical development will be very dependent in practice on military sponsorship. I shall have more to say later on the question of the subsequent stages, where actual interplanetary voyages are involved, but at this point it will suffice to say that I personally have considerable doubts about there being any genuinely valid military justification for them, even though we should probably welcome support from such quarters if it were forthcoming. To put it crudely, it might be

possible to scare the Pentagon into establishing a lunar base by convincing it that the Kremlin had similar plans—or *vice versa*—but it is doubtful whether such a possession would have any real military advantage for either, at least for several generations after it had been set up. By that time, one might reasonably hope their mutual fear of aggression, each from the other, will have been settled otherwise. This being so, we are forced to search for other motives likely to bring about the achievement of the final stages of interplanetary flight, merely observing, in passing, that national prestige might remain as a factor, even if military usefulness did not.

In this connection, it is illuminating to consider the activities which earlier cultures have regarded as being of great importance. Thus, the main preoccupation of the Ancient Egyptians was with a problematical after-life, so that the principal material remains of their civilization are the ruins of their elaborate temples and tombs; the building of the Pyramids must have represented a gigantic effort, bearing in mind the resources and facilities of the period. The comparable enterprise of the European Middle Ages was the erection of great cathedrals and monasteries, filled with works of ecclesiastical art and learning. In most periods of history, a high value has been set on artistic activities which can only be accounted as "useless" by any material standards, while many cultures, from Athens onwards, have accorded a high place to athletics and organized games of various kinds. Some would regard the inclusion of the last comparison as proceeding from the sublime to the ridiculous, but one can imagine a few devotees of the religion of cricket who would take an exactly opposite view.

In short, even the briefest survey of the above nature proves that, in every sense, man does not live by bread alone. He has other physical and psychological needs, and among the latter may be included literally anything which, at a given period, attracts his deep interest and enmeshes him in strong emotional or intellectual entanglements. We are all familiar with particular individuals who have what their fellows regard as an exaggerated passion for some particular activity, which may be growing prize orchids, playing tournament golf, writing monographs on the life and works of Francis Bacon, running a four-minute mile, cataloguing all the hundreds of varieties of fleas, or balancing the books of a chain of grocery stores. Whole nations, whole civilizations even, can also fall under the spell of a rather similar, single-minded, devotion to particular aims and objects, and these are far from universally those which promise any immediate material gain. There is no better reason for doing anything than the fact that you *want* to do it, just so long as the activity concerned does not, on balance, cause more harm than good to others. The definition of "usefulness" is therefore seen to be something that, in its broadest sense, is peculiar to individuals, or groups of individuals, living at a particular time.

The laws of natural selection have resulted in man's evolution as an intelligent animal, with the characteristics of curiosity, love of adventure and new experience, enterprise, initiative, and a tendency to respond aggressively to any challenge. These qualities, in greater or lesser degree, are present in some form in nearly all of us. Whether this is a good or bad thing is beside the point; we simply *are* like that. It should therefore not be impossible to convince man, in

time, that the exploration of space is no bizarre luxury or outlandish, wasteful, experiment, but simply a natural step forward which, sooner or later, he has to take. Even some of the most unlikely specimens of humanity show signs of accepting this view, and a new generation is growing up which very largely takes it for granted.

The enthusiasm of most youngsters for the interplanetary project is often cited, with an amused and condescending tolerance, as evidence of the juvenile nature of the whole idea. Such an attitude is particularly common among the more highbrow reviewers of modern science fiction. If such criticism was reserved for the literary (or scientific) qualities displayed by most of this sort of writing, I could usually agree, but in the matter of motivation and inspiration, I believe that youth is often showing here a greater wisdom than its elders. It would be easy to develop a convincing argument in exactly the opposite sense to the one accusing us of adolescent day-dreaming. This would draw an analogy between the youth who, on coming of age, must needs leave his home to investigate the larger world of which it is a part, and man himself, who cannot come to full maturity while remaining Earthbound. On a very long-term view, I personally am quite seriously convinced that interplanetary travel is part of the essential growing-up process for our species, a necessary advance in our spiritual, intellectual, and even material, evolution.

If such a view becomes more widespread, as I believe it almost inevitably will, then sooner or later it should be practicable to secure general acceptance for the idea that interplanetary flight constitutes one of the possible worthwhile outlets for the energies of mankind, as an alternative to the armament building which all sane people hope will be drastically curtailed within the next few generations at most. Part of the case for such a policy can be translated into at least three arguments on the hard-headed "practical" level, as distinct from any more philosophical considerations:—[11,12]

(*a*) The challenge of the exploration of space would offer a very suitable opportunity for the sublimation of those aggressive, competitive, and adventurous human impulses, and perhaps even international rivalries, which hitherto have been absorbed and dissipated in war.

(*b*) New knowledge, probably of a completely unsuspected nature, would undoubtedly be gained, and past experience shows that this would almost certainly soon find practical and commercial application. Even before this came about, legitimate widespread public interest would place a high financial value on the film, press and TV rights of the enterprise. This could, and should, be exploited to the full.

(*c*) On a purely economic level, even the gradual abandonment of the arms race would cause severe disruption to industry over a considerable period; astronautics would offer one way in which certain technical workers of various types could be maintained in employment on the sort of jobs they had been trained to do, and wanted to do. In the given hypothetical circumstances, this would probably be accepted as quite a strong "practical" argument, even though it is essentially an artificial one; some of the W.P.A. projects of the Roosevelt regime, during the depression of the 1930's, were somewhat similar in their philosophy.

Clearly the national interplanetary societies, and the International Astronautical Federation, in which they are united, have a great task of education and propaganda before them. They should feel encouraged, rather than otherwise, if the view suggested above proves to be correct, for it amounts to saying that the final and conclusive stages in the development of interplanetary flight will probably be brought about only from the same motives as those which we have held all along. Some additional encouragement may be drawn from the fact that the world has always assigned a fair degree of priority to such enterprises as exploring the Polar regions (indeed, to exploration generally), or climbing Mount Everest, or building great astronomical observatories. All of these are comparable in kind, though smaller in scale. With our increasing power over nature, it is fitting that we should proceed to more ambitious projects.

Planning the Programme

Another task, which I feel could well become a proper joint function of the interplanetary societies, is the preparation of a coherent and reasoned plan for a programme leading to the ultimate achievement of interplanetary flight. The I.A.F. should probably set up a committee to draw up such a plan, reporting annually on the progress noted towards its execution (even when made by bodies outside its own control), and modifying it as necessary in the light of the knowledge gained (for no plan should be inflexible).

I would suggest that such a plan could best be considered as consisting of three stages, or phases, and in the remainder of this paper will discuss it along those lines.

Phase I would cover the programme up to, and including, the establishment of an instrument-carrying, unmanned, satellite rocket vehicle.

Phase II would take it to the stage of achieving regular manned orbital flights around the Earth, with occasional expeditions (manned or otherwise) to circumnavigate the Moon at least.

Phase III—the final and conclusive period—would result in the achievement of true interplanetary flight, with landings on the Moon, and subsequently on Mars, Venus, and other planets (or their satellites) within our Solar System.

Any such sub-division of the programme must, to some extent, be artificial. A considerable amount of overlapping, anticipation, and (on the other hand) re-tracing of steps, will inevitably take place. Nevertheless, such a breakdown is convenient for discussion, more particularly because it will be suggested that Phase I will almost certainly look after itself, while Phase II very probably will. It is Phase III which we need to worry about, and for which we might usefully discuss a possible executive organization. From the point of view of the interplanetary societies, it is unlikely in practice that any great control could or need be exercised over Phases I and II, even though individual members of the societies will probably be responsible for the work involved. Phase III, on the other hand, is likely to need some action from the societies, before it is ever even attempted.

Phase I

Let us, for the moment, suppose that the "Phase III" organization had already been established; it would seem most desirable for it to be none other than the I.A.F. itself—or rather, some agency discharging what would, in that case, have become the principal function of the I.A.F. At any rate, it will be convenient to use those initials to describe it. Before tackling "Phase III," the I.A.F. would have needed to pass successfully through Phases I and II. During the period of Phase I, I suggest that their planners would have called for research and development work to be carried out in the following fields:—

(1) Phenomena of heat transfer and chemical equilibrium, including physical data on various gases, at stagnation temperatures up to at least 4,000° A and flow velocities of 4,000 m/sec.

(2) Phenomena of aerodynamics at Mach Nos. between 2 and 20, including those in exceedingly rarefied atmospheres.

(3) Phenomena of combustion efficiency and stability, in chambers of minimum size and weight.

(4) Development of new propellent combinations giving the highest possible specific thrusts, i.e. of around 400 secs. or more *in vacuo*, or about twice present-day values. This will involve work on such fuels as liquid hydrogen, hydrazine and ammonia, and on such oxidants as oxygen, ozone, fluorine, and various fluorine compounds—with high pressure combustion taking place at, or near to, the optimum mixture ratios. Apart from thermo-chemical problems, questions of handling and production will be introduced.

(5) Development of new materials enabling use to be made of the results of (4)—better heat-resisting steel and nickel alloys, porous sintered metals, ceramels, refractories, etc. Also, better alloys (such as those based on titanium) for the rocket structure.

(6) Development of new cooling techniques for combustion chambers, such as film or sweat cooling, again with the object of coping with the increased reaction temperatures of (4).

(7) Development of bigger rocket motors, with thrusts of perhaps 100 tons, and having improved engineering features—e.g. more efficient pumping and cooling systems absorbing less of the input propellant energy, chambers constructed by novel and lighter methods and operating at pressures up to 100 atm., etc.

(8) Development of rocket vehicle structures of novel configuration and reduced empty weight, in larger sizes than exist so far, and of multi-step construction, in some cases with wings, and in others with landing parachutes.

(9) Development of improved guidance and control devices—radio, radar, optical and servo-mechanisms, etc.

(10) In parallel with all the foregoing, and in anticipation of subsequent Phases, the theoretical study of optimum orbits, not only for satellite flights, but also for interplanetary voyages. Similarly, the preliminary study of such long-term problems of manned space-flight as the

possibility of new power-plant types (nuclear-powered and ion rockets, etc.), cabin atmosphere-conditioning, space-medicine, cosmic ray and meteor dangers, landing, navigation, and communication techniques, etc.

If we study this list, we see at once that items (1) to (9) inclusive cover exactly those problems which are already the subject of intensive research sponsored by those various military agencies anxious to secure improved rocket aircraft (of which the Bell X.1 and X.2 and the Douglas "Skyrocket" may be regarded as early examples) and missiles (of which the "Viking" is perhaps the most advanced post-war successor of the V.2). Questions of security obviously preclude any more detailed discussion of the problems concerned, but it would be idle to pretend that the above statement is less than obvious to anyone with some technical knowledge of rocketry who studies such sources as the *A.R.S. Journal*, the American aeronautical press, and the Abstracts section of the *B.I.S. Journal*. One may safely assume, therefore, that all these items are being actively worked on in the U.S.A., the U.S.S.R., the U.K., France, and perhaps elsewhere. Between the four countries actually named, or even any three of them, it is unlikely that any major point will be missed during the next decade or so.

As regards the final item (10), it will again be obvious that many of the problems listed under this broad heading are receiving at least some official attention. Space medicine, the initial transfer orbit for a satellite rocket and meteor hazard to it, and nuclear power plants in general, are cases in point. As for the rest, perusal of the pages of either the B.I.S. *Journal* or the G.f.W's. *Weltraumfahrt* will show that private members of the astronautical societies are already on the job.

It is possible that if the I.A.F. was in a position to run a Research Institute of its own, even at this present early date, then these theoretical studies would advance rather more quickly. However, in the preliminary stages of any new technological development, such work is often best left to individual inclination and inspiration; it is difficult to obtain initial ideas to order, from an organized team, even though one is essential for the further prosecution of those ideas once they have been born. If it were possible to establish some astronautical equivalent of Princeton's unique Institute for Advanced Studies, and invite various creative individuals to spend periods there during which they could meditate on their own specialized interests, then probably something worthwhile would be achieved. However, the time scale hardly demands any such arrangement; the most pressing need, for the present, is more practical data on such items as (1)–(9).

As far as these are concerned, it is extremely doubtful whether the I.A.F., even were it in a position to do so, could or would organize, at the present stage, any more (or any different) research work, as compared with that already in hand for different purposes. There would, of course, be a considerable advantage as regards freedom of publication, if the work were being sponsored by a purely interplanetary organization. However, in view of the international exchange agreements, which already operate to a large extent within the technical circles

most intimately concerned, and in view also of the fact that there is unlikely to be an embargo on *eventual* publication in any case, it is very doubtful whether this factor will be a determining influence on the course of events. Duplication of technical work, due to ignorance of the position elsewhere, has many serious disadvantages, not least that of financial extravagance. However, it also has at least one compensating advantage, in making possible a fresh approach to problems, as a result of which the "impossible" is sometimes achieved.

During this first "Phase I" of the Interplanetary Project, then, it is almost certain that military sponsorship of various other projects will, as it were, give astronautics a free ride as far as the establishment of an unmanned satellite rocket, without any special action by the I.A.F. The military will almost certainly want such a device themselves, and in fact the U.S.A. have already announced their official interest in it, at least as far as the project study stage is concerned. Whether or not the services ever become interested in true interplanetary flight, they must inevitably be concerned in due course with possible intermediate developments (even as far as those discussed in the next section of this paper, "Phase II"). The unmanned Earth-satellite-vehicle itself forms a logical ultimate stage in any high-altitude rocket research programme such as the one already in progress in New Mexico. Any government programme is likely to be subject to alternating policies of lavish spending and economizing, but in general is almost certain to show the broad trend here indicated.

The first unmanned orbital rocket will probably weigh not more than 100 tons at take-off, and be a 3-step design with a payload of only a few hundred pounds. The mission could be accomplished with conventional present-day propellents, but it is more likely that one of the newer, more energetic, combinations will be employed. In all probability, the first such missiles will not be permanent satellites at all, but will be established at a height of only some 300 km. From this position they will telemeter research data at intervals, back to their ground stations, until the very small drag acting on them reduces their velocity sufficiently to cause them to be destroyed by aerodynamic heating as they spiral down into the denser atmosphere.

This stage of achievement will, in my opinion, probably be reached by about 1965. Its total cost will be lost, in the sense of being indistinguishable, in the whole budget for military missile research and development, but will probably be about £50,000,000. This guess assumes that only about ten of this first type will be built, and the specific research, development and facility charges, peculiar to the project, amortized over that quantity.

Subsequently (and, of course, after further expenditure), larger and more ambitious guided orbital rockets of a more permanent nature will be built, for various purposes still sponsored by the military. Among these will be more advanced high-altitude research, into cosmic radiation and other subjects paying dividends in the field of nuclear physics, but it is at least possible that some operational service uses will also be included. So, we shall enter into Phase II.

Phase II

Throughout this second period, the problems remaining, and the consequent nature of the research and development work to be done, will still

be similar to those outlined at some length in the last section. They will merely represent the final (and more difficult) parts of the programmes concerned, and will almost certainly continue to be carried out by the same agencies. Thus, instead of striving for the successful handling of combustion conditions of (say) 3,000° A and 50 atm., we may have moved on to 4,000° A and 100 atm.

Our sights will also have been raised, however, as regards the practical application of this work; the target will now be the achievement of *manned* flight in satellite orbits beyond the atmosphere. I believe that a lot of extravagant nonsense has been written about the scale on which this is first likely to be attempted. The magnitude of the project will in any case be so large that every effort will be made to keep it on as modest a scale as possible.

Rather than embark on the construction of fleets of 7,000-ton vehicles, we shall probably have to be content at first with a few much smaller ones with a two-or-three-man crew. Efforts will also undoubtedly be made to economize on the new development required. Thus, before the final ships are built, even smaller versions for piloted experiments on aerodynamic braking techniques will be flown; the background obtained from the more advanced rocket aircraft of "Phase I" will be valuable here—in fact, especially as regards the human aspects of the project, the whole development must essentially be seen as a continuous and gradual building-up of experience. There will almost certainly be a tendency to concentrate on the development of one or two types and sizes of rocket motor. Different numbers of these will be used, as appropriate, in the various steps of both the earlier and smaller test vehicles and the final, larger, satellite ships.

Assuming the use of one or other of the most energetic chemical propellent combinations, a three-step ship to carry three men into a 500 km. orbit could probably be built for a take-off weight of some 500 tons. If between five and ten such ships were made, and with due allowance for the preliminary research and development work and ground facilities peculiar to this "Phase II," then the total cost of the project might be about £250,000,000. This figure might easily be increased if (for example) huge chemical production plants for some new propellent had to be constructed. However, it might reasonably be expected that these—like many of the other extensive ground facilities needed, such as the launching site—would already be substantially in existence by the time Phase II was in operation, as a result of the prior requirements of Phase I. It seems possible that a relatively small piloted Earth-satellite-vehicle might take up its orbit by about 1975.

Without being able to cite convincing reasons in detail, it also seems very probable to me that such a vehicle could be justified on the same grounds of its value as a means of gathering physical research data as the earlier unmanned orbital rockets of Phase I. That is to say, I feel that certain investigations are almost sure to arise which can be carried out efficiently only by human observers. The increasing intelligence of automatic instruments could prove me wrong in this, but the trend has certainly been revealed in other cases, if only in the sense that it has often been simpler, lighter, cheaper, and more reliable to provide a human observer than to attempt to replace him by a specialized and very complicated piece of electronic equipment. Some such instances usually occur,

especially where qualities of judgment are involved, even if the opposite is also often true.

With the primary cosmic rays continuing to provide a unique natural laboratory for study of the more fundamental aspects of nuclear physics, and with the firmly-established importance of the latter subject in human affairs, governments and their military services seem likely to continue to take a very active interest in high-altitude rocket research. There may well be, in addition, more direct military uses for piloted satellite rocket ships, circling the Earth just beyond the atmosphere, although here again I believe that a great deal of misleading publicity has been given to some such proposals.

To suggest that a vehicle of this type would constitute a permanently invulnerable platform, from which guided bombs or missiles could be launched with pin-point accuracy against terrestrial targets, seems to me to be little better than implausible nonsense. The technologies of the major powers are rarely separated by more than a few years in their stage of advancement; when we speak of some particular nation as enjoying a leading position in a given field, the lead in question is rarely worth more than five or ten years. Thus, if one country succeeded in learning how to establish a fleet of potentially offensive satellite ships, its enemy would soon learn how to send up defensive missiles to shoot them down from their permanent, calculable orbits. The same considerations apply to suggested uses of manned rocket ships, in permanent satellite orbits, for reconnaissance by radar or optical means; in any case, I imagine such observation would present severe difficulties as regards obtaining a useful degree of detailed accuracy and range—though it would perhaps be rash to suggest these could not be overcome, given the powerful military incentive.

However, the fact that they could not be invulnerable does not necessarily preclude satellite ships from having some important military uses, at some fairly distant future date; they might conceivably come to be regarded as super-reconnaissance-bombers. With some freedom of manœuvre and choice of orbit, and providing they did not linger too long in a given orbit, they might prove valuable weapons with a not-unacceptable loss rate.

Some military uses of satellite ships as ultra-short-wave radio relay stations also seems possible. Their commercial value in this connection, for long-range civil tele-communications and television transmissions, has often been emphasized by Clarke. It seems quite conceivable that this, and their other civil uses as observatories for meteorological, astronomical and other research purposes, might—given sufficient time—constitute a sufficient civil and commercial incentive in itself to bring about their achievement, even without the need for any drastic revision in the outlook and standards of value of mankind. However, long before such considerations could become effective, it seems probable that the armed services of one or more nations will achieve piloted satellite flight, and the civil applications, as usual in recent history, will follow the military.

Throughout this Phase II, therefore, it would appear that the I.A.F. is again destined to serve only as a forum for technical and other discussions and in other respects substantially to play the part of a mere onlooker.

However, the word "mere" might well be misleading, for it is truly said that the onlooker often sees most of the game. As the possibilities of the subject develop, and the next stages appear increasingly ambitious, the I.A.F. and its member-societies could exert a powerful and rising influence in leading both public and official opinion, giving prominence to the next practical step to take, with all its implications, and so on. All such work might be regarded as bridging the gap between Phases II and III of the programme. Before the I.A.F. itself has any control over a specifically interplanetary project, it could do invaluable work, ensuring that the preceding periods carry us as far as possible towards our objective. No doubt individual workers in rocketry and allied fields, who will increasingly tend to become members of astronautical societies, will operate on similar lines. There is some evidence that this was already happening even at Peenemünde!

Once piloted satellite ships exist at all, there will almost certainly be a gradual trend towards further expenditure on building more of them, in larger sizes, and to operate out to more distant orbits. For some of the practical uses of satellite rockets, for example, there is a particular virtue in the equatorial 24-hour orbit, at a radius of 42,000 km.; for radio-relay and some observational purposes, it would be an advantage for the ship to remain substantially fixed in position, relative to a given point on the Earth's surface. This trend will result in the birth of something like an astronautical industry, increasing the store of practical and detailed knowledge, and consolidating the specialized aeronautical and missile background of the earlier "Phase I."

It is often suggested that, soon after the first piloted satellite rockets have appeared, large permanent space-stations will be erected from pre-fabricated components in orbits well beyond the atmosphere. I am at least quite sure that the word "soon," in this context, must not be taken too literally; the intervening period would at any rate be nearer twenty years than five. I suspect that, in practice, these huge space-stations may not come until a much later stage in the development of astronautics, though no doubt they will eventually be built. Science-fiction authors find excellent material in their eventual uses as vacation resorts and overnight stops for transient passengers on interplanetary liners, but leaving these aside, there seem to me to be few functions of a permanent space-station which could not be discharged sooner and more cheaply, though on a much more modest scale, by the piloted satellite ships themselves. These might stay individually only a relatively short time in their orbits, to be replaced by a "relief" ship when the time came for them to reduce speed and spiral down through the atmosphere on their wings, to land back on Earth.

Smaller specialized rocket vehicles, purely for operations beyond the atmosphere, might of course be constructed in space from pre-fabricated components ferried out by the winged satellite ships. Such an orbital construction job would be far simpler than the one involved in building a big space-station, and might well be undertaken at a much earlier date. These specialized "deep-space" rocket vehicles would, of course, be refuelled and serviced from satellite ships acting as tankers or tenders and themselves designed for such specialized duties.

Schemes of this nature properly belong to the concluding Phase III, which

is about to be discussed. However, it seems to me that a few such preliminary operations might very probably be carried out towards the end of Phase II, at least to the extent of sending one or two small guided missiles, no doubt carrying television cameras, on automatic radio-controlled orbits to circumnavigate the Moon without landing. Exercises of this sort might even be extended to Mars or Venus as the object of observation, and it is even conceivable that a few expeditions by small ships, carrying human crews of only one or two, might be organized. Such missions should be just within the practical capabilities of known chemical propellents.

If they were not undertaken as part of this Phase II, then they would become one of the essential preliminaries of the succeeding Phase III. It is suggested here, however, that given sufficient public interest and support, they might just possibly be undertaken, even under the control of whatever military or other services are responsible for the earlier stages of piloted satellite flight, perhaps during the 1980's or 1990's. The motives involved would in that case be national prestige, value as operational training exercises, and the obvious research incentive of pure scientific curiosity. Some pressure from the I.A.F. and other interested astronomical and physical scientific bodies would no doubt be required. A present-day analogy is provided by the traditional part played by the armed services of both Britain and America in Polar exploration.

Phase III

It was emphasized early in this paper that the division of the programme into three phases was quite arbitrary, and merely a convenience for discussion. In truth, the groundwork for even the concluding "Phase III" is being laid even to-day. However, some thirty years from now its consideration will have become a matter of practical politics.

Before proceeding further with our analysis of the situation, it would be as well to recapitulate a few points with the object, as it were, of setting the stage. Conditions in the 1980's, as affecting our subject, must inevitably be very different from those of today. To bring home this important point, the reader is invited to let his thoughts range over the last thirty years and try to extrapolate his mind through a comparable period into the future. Since 1923, we have seen vast social and economic changes throughout the world, the final emergence of the U.S.A. and the U.S.S.R., in place of the older nations of Europe, as the dominant factors in international affairs, a great movement towards nationalism on the part of the coloured races and, in particular, the rise of India and China as great powers. In spite of obvious superficial appearances to the contrary, the period has also shown the beginnings of an encouraging trend (even if so far only a feeble one) towards rational organization of this planet, and increased international co-operation, at least between certain nations and groups of nations. On the technical side, it should be remembered that in 1923 there were no trans-Atlantic air services or television broadcasts; radar, jet-propulsion, atomic energy and large liquid-propellent rockets were quite unknown. A lot can happen in thirty years, though (on the other hand) perhaps not quite so much as some astronautical enthusiasts occasionally claim.

By the 1980's, it is tacitly assumed in this section of the paper that the world

will have begun to settle down into some sort of stable peace; at worst, into a less uneasy "cold war" with, in effect, two planets-within-a-planet tolerating each other's substantially independent co-existence—at best, into an era of real world co-operation. In either of these events, the time will be ripe for new developments. Secondly, the achievements of rocketry in the years between now and then will have made many things appear reasonable and practicable which, to a lot of people in 1953, still seem fantastic, over-ambitious, or even rather alarming. True interplanetary flight will not seem to be such a very large step forward to our sons as it does to their fathers; they, for example, will find nothing remarkable in lunching in Europe and dining in America.

Nevertheless, it seems unlikely to me that expeditions to land men on other planetary surfaces and return them safely to Earth will automatically be undertaken, by the same military agencies interested in earlier phases of the overall programme. For one thing, these agencies may, by then, be suffering a declining influence in their claims on the world's resources. Secondly, even if this is not the case, it is difficult for me to see what Earthly good a lunar or Martian base would be, in any practical military or nationalistic sense. The pun is not meant facetiously; it is quite literally true, unless one can believe this future age will attach an extravagant importance to achievements of national or racial prestige.

Popular films, books, magazine and newspaper articles, sometimes attempt to persuade us that "a nation controlling the Moon could control the Earth," because it is easier to fire a projectile from the Moon to the Earth than in the opposite direction. The latter proposition would, of course, be true, *if* one could either manufacture the necessary rockets and their propellents on the Moon, *or* if one had previously taken the trouble to ferry them there and establish an enormous stockpile on the lunar surface. Either possibility would be a gigantic undertaking, unlikely to be feasible until many years after the landing of the first small exploratory lunar expeditions. In any case, it would be far easier to build guided missiles with a range capable of reaching any point on Earth, from any other point. These will exist long before the time in question, probably with the potentiality of being launched from mobile floating or submersible bases, largely immune to the risk of prior detection.

Another suggestion is sometimes made, more or less seriously, to the effect that mining the lunar or Martian rocks might yield valuable stocks of new or strategic materials, such as uranium ore. Of course, we shall not know until we get there and, once again, shall not be able to carry out such an operation for long after that. The freight charges involved would, to say the least, be considerable, with any propulsion system we can yet envisage! Possibilities such as this are among the eventual benefits which may accrue from interplanetary travel, but they can be no more than indefinite and speculative until some very distant future date. For the next several generations, any shortages will obviously be met by the much smaller effort required to develop terrestrial alternatives; for example, if Earth finds itself short of uranium, the incentive will be towards the generation of nuclear power from more common elements.

In discussing these questions with some of my fellow astronautical enthusiasts, I sometimes detect a vague feeling that a kind of ideological inertia will carry us forward from the earlier Phases I and II, right on to completion of

Phase III. Having gone so far, this argument seems to run, how could the world at large possibly stop short of the final goal and be content merely with piloted satellite rockets? As regards "the world at large," I believe this sentiment is quite valid, but I do not believe it can be applied to the actual agencies responsible for the earlier work, except possibly (as already stated) in connection with such preliminary projects as circum-lunar flights, manned or unmanned. The I.A.F. or its equivalent will need to step in and organize world support for the final undertaking, along some or all of the lines previously discussed under the heading of "Motives."

The issue which clinches this conclusion in my mind is the fact that a great deal of further work will still be required, to bridge the considerable gap between piloted satellite flight and actual landings on other planets. Moreover, it is likely to be work that requires to branch out and extend itself in new directions. Such studies as that of reference[15] throw grave doubt on the adequacy of even the most energetic natural chemical propellents for true interplanetary flight, on any reasonable economic scale. We shall need to develop the application of nuclear energy to rocket propulsion, or the manufacture of some synthetic propellents, or the ability to stabilize and use liquid mon-atomic hydrogen, or some other new principle, as yet completely unforeseen. Of these possibilities, the employment of nuclear power seems by far the most probable, but it may not come in time to be used in the earlier Phases I and II, nor may it be necessary for their less exacting demands. It will, of course, be significant for Phase III that the use of nuclear power, for industrial purposes and the propulsion of ships (and possibly even aircraft), is likely to be fairly extensive by the 1980's. All this will help to provide a contributory background, comparable to that derived from the other preceding work on rocket aircraft, missiles and satellite vehicles.

Having cultivated a suitable supporting opinion, and when a reduction in spending on armaments permits the world to afford such a move, the I.A.F. should therefore, in my view, endeavour to secure its own acceptance as the controlling authority for the final stages of interplanetary research and development. It would then, in these respects, be established in much the same position as that occupied in this country by the Ministry of Supply, as regards aeronautical matters. In a work of fiction,[13] Clarke has described very well the functioning of the sort of body envisaged here, which he chose to call "Interplanetary."

If we continue to refer to this hypothetical future organization as the I.A.F., then we might consider that there should be I.A.F. laboratories, workshops and testing sites, distributed in various countries contributing to the work. A rather similar conception of the present day is the proposed C.E.R.N. atomic research centre in Geneva; similar ideas on astronautical research institutes are submitted in references 7 and 8. However, it seems more likely to me that use would be made of the existing organizations, again in various countries, already set up during the earlier Phases I and II.

On this view, the I.A.F. would receive funds, which might be voted in various national budgets and also obtained from various private sources, as donations or as payments for services rendered (e.g. for film, TV or journalism rights, or for technical information, etc.). As a non-profit-making organization, it would then administer the spending of these funds, giving sub-contracts for

various research, development, design and construction items to firms, universities and official establishments in different countries. The I.A.F. itself would maintain a co-ordinating technical staff, with its own project design organization. It would make whatever use it could of facilities already existing—for example, of any of the older military-sponsored satellite rockets and their crews, or of such launching sites as the Anglo-Australian range at Woomera.

Such a diffuse organization would have many obvious handicaps as regards the reconciliation of the conflicting viewpoints of different national groups, shades of technical opinion, etc. However, something of the sort would seem to be essential to spread the load around the world and ensure that the project was a truly international effort. The controlling board of the I.A.F. could consist of nominees from various national governments and societies, and its accounts subject to scrutiny by (for example) the financial department of U.N.O. It is to be hoped that its policy would remain under the control of its own top technical personnel, rather than fall into the hands of the banking and accounting fraternity who—aviation experience has shown—often exert an unenterprising and myopic influence in matters of technical development. Also, it would be necessary to ensure that its constitution enabled its top executive to take effective decisions, and not be placed in a position of great responsibility and little authority. "Government by committee" has many pitfalls.

Technically, the task of the I.A.F. would be to extend the achievements of Phase II, undertaking the development of larger and improved piloted satellite rockets and the despatch of expeditions to circumnavigate the Moon without landing, as necessary. The extent of these preliminaries would, of course, depend on the progress previously achieved. Work would need to proceed in parallel on the new propulsion units, probably of nuclear type, and finally specially-designed ships to take these would need to be built and assembled in orbits beyond the atmosphere, where they could be serviced, probably by chemical satellite ships. After trials in space, with progressively longer voyages, an expedition would be despatched to the Moon. Probably the main nuclear ship would orbit the Moon, while a landing was made on the surface in a small tender rocket, using chemical propellents. At a later date, similar expeditions would visit Mars, Venus, and other possible destinations, using more advanced ships subsequently developed.

Once again, I should like to register the most emphatic opinion that the first such interplanetary expeditions will be relatively modest affairs, with single ships carrying only two or three men. If these have a nuclear propulsive system capable of a specific thrust of c. 1,000 secs., or perhaps an ion-drive greatly exceeding such a performance, then their starting weight might be less than 1,000 tons. Some of the grandiose conceptions so far publicized[3,4,5] ignore the realities of the situation, and seem to assume that almost unlimited support for astronautics will, quite suddenly, be forthcoming. It will not; it must be allowed to develop gradually, and in the meantime mankind will have many projects competing for attention, at least equal in value and priority.

If the interplanetary project enters its final Phase III in the 1980's, it would seem reasonable to expect that the first successful lunar expedition might be made in about 2,000 A.D., as a fitting climax to a wonderful century of science.

Its cost cannot, of course, be estimated with any reasonable accuracy today. It might well lie, however, anywhere between £500,000,000 and £1,000,000,000, with a need for the further expenditure of even greater sums before the other planets could be reached. Subsequent voyages to any given destination would, of course, be much less expensive than the first one, since the ships and supporting facilities would already exist.

Conclusions and Recommendations

The conclusions of this paper may briefly be summarized as follows:—

The early phases of a programme leading to interplanetary flight will probably be sponsored by national military services, as a logical extension of their present missile, aircraft and high-altitude research activities. This is, in fact, already happening; it would not be practicable for any specifically interplanetary organization to intervene, and even if it could, it is unlikely that the present rate of progress would be appreciably accelerated. These early phases, up to the achievement of piloted satellite flight, are within the capabilities of existing technology, using chemical propellents.

The later phases of the programme, however, will probably involve the use of nuclear power or some other major new development. They will have little or no military usefulness, and hence will not be attempted until sufficient public support for them, in their own right, is awakened.

Such conclusions lead to the following recommendations:—

The interplanetary societies, through their International Astronautical Federation, should take the initiative of establishing a Programme Committee, to study the progress made during the early phases and point the way to its ultimate application for true interplanetary flight.

In preparation for this ultimate aim, the interplanetary societies and their I.A.F. should concentrate on awakening and stimulating public support, in readiness for the time when a specifically interplanetary project can be undertaken. When that time comes, the I.A.F. should endeavour to be accorded responsibility for administering the project and spending the sums voted for it by various nations. In most cases, the actual technical work involved could probably best be sub-contracted to existing specialized organizations in various different countries, though remaining under I.A.F. control.

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APPENDIX A.

Time Scales

The best (indeed, the only) way of forming a reasonable estimate of the astronautical future is to study the precedents of the past. In doing this, it should be remembered that the next step forward always looks more daring and revolutionary than does the last one in retrospect. Also, the following three facts should be borne in mind, as they indicate that the trends involved are likely to be rather more complex than a simple case of history repeating itself:—

(i) From (say) 1800 to 1900, progress was relatively slow. This was because, prior to the nineteenth century, there existed no ready-made background of scientific knowledge and technical skills, supporting industry, or demand for the products of technology. All these things were being created during this period.

(ii) From (say) 1900 to 1950, the rate of progress was greatly accelerated. By that time, the background referred to in (i) did exist; in particular, there was a tremendous demand for the results of applied science, considerably stimulated by two World Wars.

(iii) There is some evidence that the rate of progress may now slacken off, if only because all the relatively cheap and easy things have been done, and only immensely difficult and costly projects remain to be attempted. This, of course, is a considerable over-simplification, offset to some extent by the

greater resources now available. However, there is no doubt (for example) that it takes very much longer to design and develop a modern trans-sonic aeroplane and its gas turbine power plant than it did for the corresponding aircraft of the 1930's.

An incidental but inescapable conclusion from the data which follow is that no nation has had a monopoly of contributions to scientific and technological progress.

EXAMPLE TIME-SCALE NO. 1

The Aeroplane

Cayley's theoretical writings, model glider experiments, etc. (British)	*c.* 1810
Henson and Stringfellow's powered models (British)	*c.* 1845
Founding of Royal Aeronautical Society (British)	1866
Lilienthal's piloted gliders (German)	*c.* 1895
First successful light i.c. engines: Daimler and Benz (German), etc.	1895
First successful piloted powered flights: Wright Bros. (American)	1903
Bleriot flies English Channel (French)	1909
First successful all-metal aircraft: Junkers (German), etc.	1915
First non-stop trans-Atlantic flight: Alcock and Brown in Vickers "Vimy" (British)	1919
First regular cross-Channel airlines	1919
Douglas D.C.2 (American)—which might be regarded as the first genuinely commercial airliner	1933
First turbojet engine: Whittle (British)	1937
First trans-Atlantic airlines: semi-experimental	1939
regular	1946
First flight with turbojet propulsion: Heinkel (German)	1939
First supersonic level flights: Yeager in rocket-propelled Bell X–1 (American)	1947
First turbojet airline services: "Comet" (British)	1952

EXAMPLE TIME-SCALE NO. 2

Whittle Type (Centrifugal Compressor) Turbojet Aero-Engine

Whittle's first thesis on jet propulsion	1928
„ „ patents	1930
Practical experiments started	1936
First engine ran	1937
First flight (W.I.X. in Gloster E.28/39)	1941
First engines in military service (Rolls-Royce "Wellands" in Gloster "Meteors")	1944
First engines in commercial service (D.H. "Ghosts" in D.H. "Comet")	1952

EXAMPLE TIME-SCALE NO. 3

Typical Advanced Modern Aircraft—De Havilland "Comet" (Series I)

Design studies of "Ghost" engine started (for various aircraft installations)	1943
Design studies of "Comet" started (various layouts investigated—3 and 4 engines, straight and swept wings, twin-boom, tailless, etc.)	1945
First test-bed running of "Ghost" engine	1945
"Comet" design layout substantially settled	1946
First experimental flying of "Ghost" engines (in "Vampire" and "Lancastrian")	1947
"Comet" first flight	1949
"Comet" started route-proving trials	1951
"Comet" entered airline service	1952

EXAMPLE TIME-SCALE NO. 4

Nuclear Energy

Radio-activity discovered by Becquerel (French)	1896
Electron discovered by Thomson (British)	1897
Quantum theory: Planck (German)	1901
Equivalence of mass and energy implied by Special Relativity Theory of Einstein (German)	1905
Isotopes discovered: Soddy and Thomson (British)	*c.* 1910
Atomic structure hypothesis of Rutherford (British) and Bohr (Danish)	*c.* 1912
First experiments on nuclear disintegration: Rutherford (British)	1919
First artificial disintegration of atomic nucleus: Cockroft and Walton (British)	1932
Neutron discovered by Chadwick (British)	1932
Nuclear fission of uranium discovered by Hahn and Strassmann (German)	1938
Nuclear fission theory developed by Frisch and Meitner (German), Bohr (Danish) and Wheeler (American)	1939
Free neutron production in uranium fission experimentally proved by Joliot, Halban and Kowarski in France, and by Anderson, Fermi, Hanstein, Szilard and Zinn in U.S.A.	1939
Allied effort on atomic energy concentrated in U.S.A., and "Manhattan Project" set up	1941
First controlled self-sustaining chain reaction in atomic pile: Fermi: (Italian), etc., in U.S.A.	1942
Explosion of first nuclear fission bombs: New Mexico test, followed by Hiroshima and Nagasaki operations	1945
Independent British research into practical applications of nuclear energy re-started; probably simultaneous (or earlier) start of Russian effort	1946
Explosion of first Russian atomic bomb	1949
" " " British " "	1952
Useful (electrical) power first generated on small scale from nuclear reactor; A.E.C. National Reactor Testing Station, Arco, Idaho (American)	1951
Explosion of first atomic bombs using thermo-nuclear reaction: American	1952
Russian	1953

The rapid progress in atomic bomb development revealed by the above dates, in spite of the necessary immense technical effort, is of course explained by the incentive involved.

EXAMPLE TIME-SCALE NO. 5

Rocketry and Astronautics to Date

First powder rockets (Chinese)	*c.* 1200
War powder rockets of Congreve (British)	*c.* 1805
First liquid propellent rocket motor: Paulet (Peruvian)	1895
Pioneer theoretical studies of astronautics, published as classic works:—	1900–1935
"The Rocket into Cosmic Space": Ziolkovsky (Russian) 1903	
"A Method of Reaching Extreme Altitudes": Goddard (American) 1919	
"Wege zur Raumschiffahrt": Oberth (German-Rumanian) 1929	
"L'Astronautique": Esnault-Pelterie (French) 1930	
"Raketenflugtechnik": Sänger (Austrian) 1933	
—also Von Pirquet, Hohmann, etc.	
Practical small-scale pioneering experiments with liquid propellent rocket motors and missiles by V.f.R. and A.R.S., etc.; also early tests with rocket-propelled gliders, etc.	1925–1935
First liquid propellent rocket missile; Goddard (American)	1926

Founding of pioneer astronautical societies:—	
Verein für Raumschiffahrt (German)	1927
American Interplanetary Society (now A.R.S.)	1930
British Interplanetary Society	1933
German military rocket research establishment set up at Kümmersdorf	1933
Moved to Peenemünde	1937
First piloted rocket aircraft:—	
Modified Ju.50, He.112 and He.176 at Peenemünde	*c.* 1939
Messerschmitt 163 (German)	1941
Northrop XP–79 (American)	1944
First successful flight of Peenemünde's A.4 rocket missile (V.2): von Braun (German)	1942
First operational use of V.2	1944
Bell X–1 piloted rocket aircraft exceeds speed of sound (American)	1947
V.2/WAC Corporal two-step rocket reaches 242 miles altitude (American)	1949
Martin "Viking" single-step rocket reaches 135 miles altitude (American)	1951
Douglas "Skyrocket" piloted rocket aircraft flies at approx. twice speed of sound and 15 miles high (American)	1952

APPENDIX B.

Costs

(£1 = 2.80 dollars.)

To amplify those quoted in the text, certain other figures on the costs of modern technological projects are given below. Together, they form the basis of the guesses made in this paper for the probable costs of astronautical development. If anyone is sufficiently interested to re-read this survey at some future period, it is to be hoped (in view of continuing inflationary trends) that they will bear in mind that the figures quoted here relate to mid-twentieth century values.

1. Some Miscellaneous Data on Overall Costs

(*a*) The U.S. journal "Army Ordnance" (March-April, 1947) stated that the German government spent more than £100,000,000 over a period of 10 years to develop V.2.

(*b*) Recent statements to the U.S. Congress have suggested that the total cost of the giant aircraft carrier "Forrestal," with its nuclear power plant, will be about £80,000,000. Also, that the similar project to build two very large nuclear-powered submarines will account for about £20,000,000—apart from the cost of their engines, which will nearly double the price.

(*c*) The total cost of the project that involved the building of six Douglas D.558 supersonic research aircraft (the last version of which was the "Skyrocket") has been published as over £4,000,000.

Recent British Parliamentary statements have revealed that £6,500,000 was spent here on the project for the giant "Brabazon" airliner, plus another £6,000,000 for ground facilities (hangar, runway, etc.), and that an additional £2,000,000 would have been required to complete the second prototype (now abandoned) with "Proteus" gas turbines. Also, the programme of gas turbine development at Bristol leading to the "Proteus" turbo-prop (also scheduled for the "Princess" flying boat and the "Britannia" airliner) has cost over £10,000,000 in the period 1944–1952.

(*d*) Aeronautical costs are particularly interesting as they are most comparable to the astronautical case. A clear distinction should always be made between the very high prototype aircraft costs, which include design, research and development charges spread over only a few units, and production costs for larger quantities. Also, it should be remembered that even unsuccessful prototype projects rarely represent a complete waste of money. Experience gained with them makes a contribution towards subsequent designs, so that it is very difficult to say exactly

what the fair cost of any particular project is; it will always owe a great deal to its background, in the continuous process of aeronautical development. The same will be true of astronautics.

However, the cost of modern aircraft is still very high, even when they are built in fair quantities. Recent British data suggests that even a modern single-seat fighter, with its turbojet engine and fully-equipped, costs about £100,000 (e.g., the "Hunter" or the "Swift"). What would now be regarded as a medium-sized four-jet aircraft (such as the "Comet" airliner or the "Valiant," "Victor" or "Vulcan" bombers) raises this figure to between £500,000 and £1,000,000.

Due to heavier labour charges, American costs are even higher. For example, Boeing have estimated that their projected Type 707 jet airliner will cost about £1,400,000 in production quantities. The cost of their much larger B.52 eight-jet bombers has been quoted as about £5,000,000 each, based on a small production order for 70 aircraft. Over 300 have been built of the older B.36's, to be replaced by the B.52, but the cost of each of these Convair aircraft nevertheless remains at £1,250,000.

2. Cost per lb.

As a preliminary approximation, the expense of any comparable technical devices may be considered as roughly constant on a "£ per lb." basis. (Obviously, a wrist watch costs more per lb. than a steamroller—hence all the qualifications.)

References 16, 17 and 18 are in general agreement in estimating the following contemporary figures for aircraft:—

£50 to £70 per lb. empty* weight for prototypes, including all design and development costs up to stage of operating trials.

£4 to £10 per lb. empty* weight in production, depending mainly on quantity but to some extent on type.

As already stated, American costs are higher still. A. M. Mayo of Douglas has even estimated ("American Aviation," 20/7/53) that they correspond to about £180 per lb. for prototypes, and down to £18 per lb. in production.

Automobile costs vary between £0·15 and £1·5 per lb. empty weight (without Purchase Tax!), with most types in large production close to £0·25 per lb. It becomes practically meaningless to distinguish between "prototype" and "production" costs for shipping, since it is only rarely that more than a few ships are built to a given design, and in any case the product is much more of a hand-built article. British shipping costs vary between £0·05 and £0·15 per lb. unladen displacement. Both these examples, of course, reflect the relatively small case for weight economy in the vehicles concerned.

There appear few reasons to expect the cost of spaceships and rockets to be very much less than for aircraft, since all will employ the same light and expensive construction. In fact, the only such argument of any great force would seem to be that a larger percentage of the empty rocket weight would consist of relatively simple structure, such as propellent tanks. Moreover, in the phases of astronautical development relevant to this paper, it is unlikely that very large numbers of any single design will be built. (These conclusions may not be valid for "one-shot" expendable military missiles produced in large quantities, but these do not concern us here.)

Therefore, it has been assumed that a figure of about £50 per lb. empty weight will apply. This is supposed to cover preliminary ground testing, and general development costs peculiar to the particular project, but further arbitrary allowances have been made to cover basic research and special ground facilities which would probably be required, over and above those already in existence which could be used.

* *i.e., gross or all-up weight minus crew, payload, and fuel; figures are sometimes quoted per lb. gross weight for aircraft, but have been corrected here. (Very roughly, the fully-equipped empty weight = 50 per cent. to 70 per cent. of the gross.)*

3. Propellent Costs[10]

These will form no small part of the cost of any rocket project, and should therefore not be overlooked in any independent study of the subject. It should also be remembered that prior development of the motors on the ground may account for anything between 10 and 100 times the consumption of the motors on a particular operational mission—perhaps even more, if the motor concerned is a radical departure from previous practice.

Chemical rocket propellents currently in use vary in price from about £30 per ton for kerosine, acid or oxygen, up to nearly £200 per ton for the newer oxidants (such as hydrogen peroxide), and several thousand pounds per ton for highly experimental propellents such as anhydrous hydrazine as fuel, or fluorine compounds as oxidants. With increasing use, the higher figures will obviously drop, though the most powerful propellents are likely to remain fairly expensive.

Perhaps a mean eventual figure of £100 per ton would not be very far wrong for the most energetic propellents, as a rough conception.

4. Astronautical Costs

The literature contains many previous estimates of the cost of astronautical projects, ranging from a highly unrealistic pre-war B.I.S. claim that a lunar expedition would cost no more than a single destroyer, up to the suggestions of Sänger.[6] He thought that a lunar spaceship would cost about the same as a large aircraft carrier or an armoured division, and that the establishment of a large manned space station would account for about 10 per cent. of the annual U.S. defence budget. A large-scale manned expedition to Mars would require the equivalent of a whole year's work potential for mankind, unless the space station already existed as a refuelling point; if it did, the cost would be about the same as that to establish a large navy and would come within the capacity of a single big nation.

Von Braun has committed himself to a number of quite specific estimates.[3] Thus, he believes that £1,400,000,000 would pay for the establishment of a very large space station, including the fleet of a dozen or so piloted satellite rockets required to service it and as a preliminary to its construction. (For each of these 7,000 ton monsters, he allows only £1,400,000). A further £180,000,000, von Braun thinks, would finance an expedition by 3 giant spaceships to the Moon, using the space station as their point of departure and return.

In the opinion of the present writer, von Braun's figures are decidedly optimistic for colossal schemes of any such grandiose conception as his. For example, his 7,000 ton satellite ships are alleged to have an empty weight of nearly 1,000 tons; by the aircraft cost arguments of section 2 of this Appendix, this would imply a cost of between £8,000,000 and £140,000,000 each, depending on the quantity built, rather than £1,400,000. Other optimistic assumptions (as regards performance, mass ratio, recovery of discarded lower steps, etc.) are also made in the references of 3; all these reflect on the economics.

ENTRY INTO CIRCULAR ORBITS—2

By Derek F. Lawden, M.A.

SUMMARY

The problem of navigating a rocket approaching a planet from a great distance, into a circular orbit about the planet with minimum fuel expenditure, is analysed. The effects of varying the line of approach and the radius of the circular orbit are considered.

The problem of transferring a rocket from a point just outside the atmosphere of a planet, at which its velocity is prescribed, into a circular orbit about the planet with a minimum expenditure of fuel, has been considered in an earlier paper.[1] The present paper analyses manoeuvres whereby a circular

orbit may be entered by a rocket approaching a planet from a great distance. We shall assume that the plane of the rocket's motion during its approach is coincident with that of the circular orbit to be entered.

The solar gravitational field will be sensibly uniform in the neighbourhood of the planet and, during the manoeuvre, both rocket and planet will be in a state of free fall in this field. It follows that the presence of the solar field will not be detectable by observations confined to the system "planet + rocket" and may be ignored throughout the calculation. To an observer on the planet, the rocket will appear to approach from infinity along one arm of a hyperbola with focus at the planet's centre and, unless action is taken by the rocket crew, the ship would later be seen to recede to infinity along the other arm of the hyperbola, with a speed equal to that of its approach. Except in the vicinity of the planet, the rocket's track will be an ellipse with the sun at a focus, this ellipse being, perhaps, the Hohmann ellipse tangential to the orbits of the planet of origin and planet of destination. If the rocket has travelled from a planet proceeding around an orbit smaller than that of the target planet, its velocity in the Hohmann ellipse will be smaller than that of the latter planet in its orbit and the rocket will appear to the observer to approach from the direction in which his planet is moving. Otherwise it will appear to overtake the planet. It is unlikely that the line of approach from infinity will pass through the planet's centre, since, even if this were desirable and an attempt was made at the orbit of departure to place the rocket in a Hohmann ellipse which would satisfy this requirement, a negligible error in the initial conditions would be sufficient to shift the line of approach laterally through many thousands of miles. We may expect that during the long journey between the two planets, small velocity corrections will be made at selected points with negligible expenditure of fuel, to ensure that the line of approach is that most suited to the manoeuvre we are about to examine. The velocity of approach, on the other hand, must be regarded as a fixed quantity which can only be appreciably altered by gross expenditure of fuel. Given a velocity of approach, there are four types of situation:

(*a*) To enter a circular orbit of given radius, the line of approach being specified.

(*b*) To enter a circular orbit of given radius, the line of approach being open to choice.

(*c*) The line of approach being given, to enter a circular orbit whose radius is open to choice.

(*d*) To enter a circular orbit of arbitrary radius from an arbitrary line of approach.

In each case the problem is to select values for the variable quantities to ensure minimum fuel expenditure during the manoeuvre.

In Case (*a*) we have to transfer from a given hyperbolic orbit into a given circular orbit and, it follows from the general analysis of the problem of transfer between two conic orbits given in a previous paper,[2] that this is most economically achieved via an ellipse of transfer tangential to the circle and to the hyperbola at its apse. Impulsive thrusts are to be applied at both points of contact

to effect transfer, firstly, from the hyperbola into the ellipse and secondly, from the ellipse into the circle. Fig. 1 (*a*) indicates a transfer of this type.

Case (*b*) need not detain us long either, for this is a problem identical mathematically with that already analysed in reference (3). There the requirement was to escape to infinity from a given circular orbit with minimum fuel expenditure, i.e., the order of events was the reverse to that here envisaged, but otherwise there is a complete parallel. The result of the analysis, as applied to our present situation, is that if the velocity of approach is less than the escape velocity at a point on the circular orbit, the line of approach should be selected so that the hyperbola is tangential at its apse to the circular orbit.

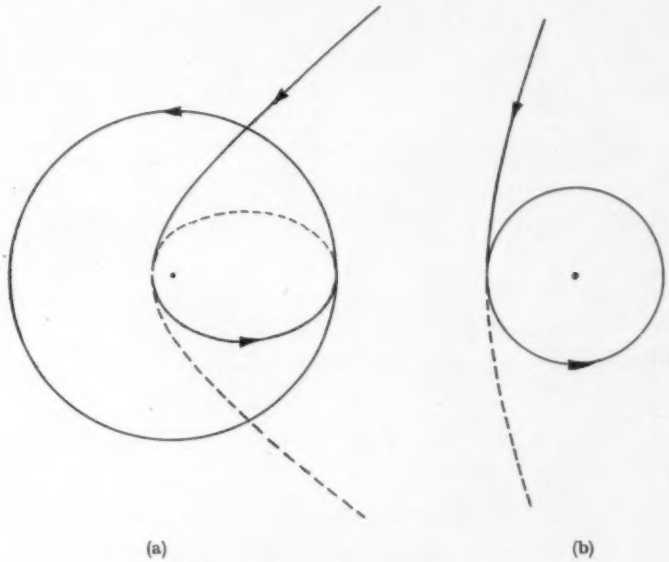

FIG. 1. Trajectories of entry into a circular orbit.

A single impulsive thrust at the apse, then suffices to effect transference as illustrated in Fig. 1 (*b*). If, however, the velocity of approach is greater than the aforesaid escape velocity, the line of approach should be directed so that the apse of the hyperbolic orbit is as close as possible to the centre of attraction, i.e., just outside the planet's atmosphere. An impulse at the apse effects transference into an ellipse tangential to both the hyperbola and the circle, and a second impulse later effects transfer into the circular orbit (Fig. 1 (*a*)).

In Case (*c*), employing the notation of reference (3), b, the apsidal distance for the hyperbolic orbit, is given, whereas a, the radius of the circular orbit, is to be selected so as to minimize fuel expenditure. For a particular value of a, we transfer as indicated in Fig. 1 (*a*), and the characteristic velocity V for

the manoeuvre is given by equations (7) of reference (3). With $x = b/a$, these equations may be written,

$$V = \left(\frac{\mu}{b}\right)^{\frac{1}{2}} \left\{ x^{\frac{1}{2}} - \sqrt{2}(1+x)^{\frac{1}{2}} + \sqrt{2} + \lambda \right\} \quad x \leqslant 1$$

$$= \left(\frac{\mu}{b}\right)^{\frac{1}{2}} \left\{ \sqrt{2}(x-1)\,(x+1)^{-\frac{1}{2}} - x^{\frac{1}{2}} + \sqrt{2} + \lambda \right\} \quad x \geqslant 1 \qquad (1)$$

μ/r^2 being the intensity of attraction at a point distant r from the centre of the planet and λ being given by

$$\lambda = \sqrt{2}\left\{ \left(\frac{bU^2}{2\mu} + 1 \right)^{\frac{1}{2}} - 1 \right\} \qquad .. \quad .. \quad .. \quad .. \quad .. \quad (2)$$

where U is the velocity of approach. λ is clearly always a positive quantity.

Defining w to be the dimensionless quantity $V(b/\mu)^{\frac{1}{2}}$, and plotting w against x, we obtain a graph of the shape shown in Fig. 2. We have taken $\lambda = 0$ in

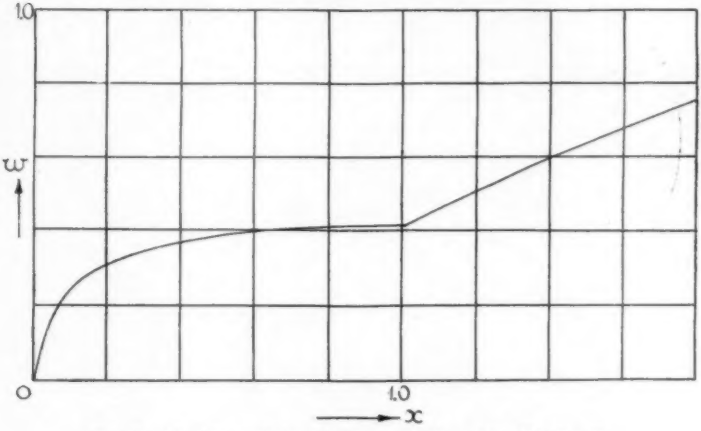

FIG. 2. Variation of characteristic velocity with orbital radius.

this figure, but the graph for any other value of λ is easily obtained from that given by raising it parallel to the w-axis through a distance equal to λ. It is clear that for all values of λ, i.e., for all given velocities of approach, w decreases, and hence the fuel expenditure decreases as we decrease x. This implies that it is always advantageous under these circumstances, to increase a as far as possible. When approaching a planet which it is desired to circumnavigate therefore, as large a circular orbit as possible, consistent with requirements of visibility, should be selected and this should then be entered by the manoeuvre illustrated in Fig. 1 (*a*). With $x = 0$, we find that

$$V = \left(\frac{\mu}{b}\right)^{\frac{1}{2}} \lambda = \left(U^2 + \frac{2\mu}{b} \right)^{\frac{1}{2}} - \left(\frac{2\mu}{b} \right)^{\frac{1}{2}} \qquad .. \quad .. \quad .. \quad .. \quad (3)$$

This expression represents the lower bound to the velocity change necessary to effect a manoeuvre which will result in a circular circuit of the planet.

b will not be observable directly from the rocket. If, however, observations are made to give p, the perpendicular distance of the planet's centre from the asymptote of approach (i.e., the minimum distance of approach of the rocket to the planet's centre, if the latter's attraction were inoperative), then, in view of the constancy of the angular momentum over the hyperbolic arc, we have the equation

$$Up = vb, \quad .. \quad .. \quad .. \quad .. \quad (4)$$

where v is the velocity at the apse. The energy equation of the hyperbolic orbit yields

$$\tfrac{1}{2}v^2 - \tfrac{1}{2}U^2 = \frac{\mu}{b} \quad .. \quad .. \quad .. \quad (5)$$

and hence, eliminating v between these equations, we obtain

$$b^2 + \frac{2\mu}{U^2}b - p^2 = 0 \quad .. \quad .. \quad .. \quad (6)$$

Whence

$$b = \left(\frac{\mu^2}{U^4} + p^2\right)^{\frac{1}{2}} - \frac{\mu}{U^2} \quad .. \quad .. \quad (7)$$

b can now be calculated.

EXAMPLE

A rocket approaches Jupiter along the Hohmann ellipse from the Earth's orbit, its line of approach being displace 10^6 *miles from the planet's centre. Calculate the lower bound of the characteristic velocity for a manoeuvre into a circular orbit and compare this with the characteristic velocity required for optimum transfer into the orbit of J.IX.*

Given two circular orbits A and B and the Hohmann ellipse tangential to both, it may be shown that if q is the velocity in the circular orbit A and if Q is the velocity in the Hohmann ellipse at its point of contact with A, then

$$\left(\frac{q}{Q}\right)^2 = \tfrac{1}{2}(1 + r), \quad .. \quad .. \quad .. \quad (8)$$

where r is the ratio of the radius of the circular orbit A to that of B.

The velocity of Jupiter in its orbit is 8·11 miles/sec. and the ratio of the radius of the Earth's orbit to that of Jupiter is 1 : 5·2. Hence $r = 5{\cdot}2$ and equation (8) shows that the velocity in the Hohmann ellipse at Jupiter's orbit is 4·60 miles/sec. The relative velocity of approach of the rocket to Jupiter will accordingly be $U = 8{\cdot}11 - 4{\cdot}60 = 3{\cdot}51$ miles/sec.

For Jupiter's gravitational field $\mu = 3{\cdot}04 \times 10^7$ miles^3 sec.$^{-2}$. Since $p = 10^6$, it follows from equation (7) that $b = 195{,}000$ miles.

Equation (3) now yields the lower bound of the characteristic velocity to be 0·34 miles/sec.

The radius of the orbit of J.IX is $a = 15 \times 10^6$ miles and hence $x = b/a = 0{\cdot}013$. Substituting in equation (2), we calculate that $\lambda = 0{\cdot}028$ and hence

from the first of equations (1), the characteristic velocity for the transfer into the orbit of J.IX proves to be 1·66 miles/sec.

Consider finally Case (*d*). For a given line of approach, it is most economical to transfer into a circular orbit of the largest possible radius. Equation (3) gives the characteristic velocity V for such a manoeuvre. Now, varying the line of approach, we have to choose b so that V is minimized. It is easily shown that V, as given by equation (3), decreases steadily as b is decreased. b cannot be made less than the radius P of the planet and hence the minimum characteristic velocity is

$$\left(U^2 + \frac{2\mu}{P}\right)^{\frac{1}{2}} - \left(\frac{2\mu}{P}\right)^{\frac{1}{2}}. \quad .. \quad .. \quad (9)$$

For Jupiter $P = 44{,}500$ miles and hence, for the approach via a Hohmann ellipse from the Earth's orbit, the characteristic velocity for a transfer into a circular orbit must be greater than 0·167 miles/sec.

The value of p when $b = 44{,}500$ miles, is found from equation (6) to be $4{\cdot}71 \times 10^5$ miles.

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CONFERENCE ON ROCKET EXPLORATION OF THE UPPER ATMOSPHERE

Oxford, August 24-26, 1953

By J. Humphries, B.Sc.(Eng.), A.M.I.Mech.E., A.F.R.Ae.S.

This conference, which was organized by the Royal Society, was attended by 80 of the world's leading upper atmosphere scientists (and about half of the B.I.S. Council!). The importance of the atmosphere in astronautics needs little stressing since it is likely to be a great hindrance on the way out, and may have to be put to use for braking purposes on the way back. Besides the intrinsic interest in the upper atmosphere, most of the papers described rocket techniques—as the title of the conference indicates—and two of them discussed the possible use of instrument-carrying artificial satellites.

During the past six years, about 30 tons of instruments have been carried aloft in V.2's, Aerobees and Vikings to altitudes up to 242½ miles, and vast quantities of data have been obtained. The papers delivered covered not only the determination of the variation of pressure, density and temperature with altitude, but also the distribution of ozone, electron concentration, long-range radio propagation, high altitude winds, and so on. One of the drawbacks to rocket sounding is the expense of the vehicle. Even the simple Aerobee, which is powered by a liquid-propellant rocket motor and is capable of lifting a 150 lb. payload to a height of 75 miles, costs $25,000—without instrumentation; a figure as high as $400,000 was quoted for the much larger Viking. This is a lot of money for one or two minutes' recording time, and Dr. J. A. Van Allen,

of the State University of Iowa, has developed a cheap scheme for getting small payloads to a great height. It consists of lifting a small instrumented rocket to some 50,000 ft. altitude by means of a balloon and then firing it in a near vertical direction. In this way the high drag due to firing through the lower atmospheric layers is avoided, and almost the theoretical vacuum performance of the rocket can be achieved. During this past summer, payloads of 30 lb. have been sent up over Baffin Bay to heights of 60 miles in an effort to study cosmic rays near the geomagnetic pole. The cost of such a balloon and rocket combination—or "rockoon" as it is sometimes called—is only $1,200 and it is hoped that this is low enough to enable certain studies to be undertaken on a synoptic basis.

One other major drawback to the use of the rocket in upper atmosphere research is the very short time during which it is in the region of interest—two or three minutes at most. For many experiments this is insufficient, and a great deal more could be accomplished if a stable platform could be established outside the earth's atmosphere—in other words, an instrument-carrying artificial satellite. Dr. Fred Singer, of the U.S. Naval Research Laboratory, said that although the intial cost of such a project would undoubtedly be very high, the cost per minute of recording time, if power were available for several days' experimental work, might very well be quite reasonable. The general feeling was that the time was not quite ripe to begin work, but that a few years' work by the guided missile people might well solve many of the outstanding problems of propulsion and guidance. In any case, it was agreed that there were many years of work ahead using conventional sounding rockets.

It is only in rare cases that an upper air parameter can be measured directly, and great ingenuity has been exercised in obtaining the necessary data to allow the various properties to be calculated. One of the main difficulties to be overcome in trying to obtain readings at various altitudes, is that the rocket is either traveling very rapidly upwards or very rapidly downwards! This means that normal instruments have insufficient time to reach equilibrium readings. For example, none of the standard methods of measuring temperature is of any use, and various subterfuges have been resorted to. One of these is the measurement of the Mach angle of the shock wave produced by the nose cone of the rocket or by a wedge, from which the Mach number and hence the temperature may be deduced. Of various techniques to determine the Mach angle only one has met with success. An array of movable probes, each provided with a pressure pickup, is mounted near the nose of the rocket. Each time the pickup moves through a shock-wave, a signal is produced, hence the Mach angle can be deduced from the known position of the probe.

A completely different approach has been developed by the Signal Corps Engineering Laboratories. Grenades weighing 4 lb. each are ejected from an Aerobee at predetermined heights. Cameras on the ground record the flashes, and thus enable the spatial co-ordinates of the explosions to be determined. The times of arrival of the sound waves at the ground are measured with a microphone array. With this data the mean speed of sound in the layers between the explosions can be calculated, and hence the mean temperature. The same method can be used to determine average wind velocities from the

effect of the wind on the downward travelling sound waves. The wind directions in the upper atmosphere over White Sands Proving Ground, New Mexico have been found to be easterly in summer and westerly in autumn and winter. The wind speeds appear to reach a maximum at 55 km. altitude, the highest measured speed being 102 m./sec.

Perhaps of greatest interest to the Society are the experiments for detecting micro-meteorites. In the method developed by the Naval Research Laboratory, a highly polished metal plate is exposed at high altitude, and its surface is examined microscopically for small pits caused by the impact of micro-meteorites. Fortunately, the number is very small, and the effect on a space mirror used for providing power would not be noticeable for a considerable period. Another method is that developed by Temple University and tested on two occasions in a modified V.2. A crystal microphone is mounted flush with the skin of the rocket, and is connected to an amplifier tuned in the ultrasonic region from 30 to 60 kcs., with a bandwidth of about 10 kc.—the microphone also has its maximum sensitivity in this region. Such an arrangement is sensitive to the very high frequency vibrations caused by the impact of minute particles, but insensitive to any extraneous noise of a low frequency. In the more successful of the two tests, a total of 66 impacts were recorded between 70 and 214 seconds after take-off—that is, between 40 and 140 km. altitude. This corresponds to a rate of one impact every 2.2 seconds per square foot. Whipple has estimated that the collision rate that would be detected by acoustical means should be about one impact every 1.1 seconds per square foot. These figures are in good agreement for this type of work.

The overall picture gained at the Conference was that, considering the technical problems of getting equipment aloft, making it work under exceptionally difficult circumstances, and the complexity of the data so obtained, the amount of knowledge amassed in six years was highly creditable. It must be remembered, however, that this has involved a huge number of workers, and an outlay of millions of pounds. Such work could not progress without Government backing. The basic physical properties of the atmosphere, namely pressure, density and temperature are now moderately well known at certain latitudes up to 110 km., but even here there is room for some doubt. The more abstruse properties such as electron density, winds and air-glow and the properties of solar and cosmic radiation at high altitudes have only just been touched upon, and many more years of upper atmosphere research by rocket will be needed before some of the problems facing the upper air scientists are unravelled.

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ROCKETS AND THE UPPER ATMOSPHERE

By Homer E. Newell,* Junr.

(*A Summary of an address to the British Interplanetary Society in London on August 29, 1953.*)

Many years ago scientists began to think of rockets as a means of doing experiments in the high atmosphere. An impelling motive behind Goddard's early rocket work, for example, was the desire to study the upper atmosphere at first hand, and when large rockets did become available, as a result of missile developments during World War II, they were quickly put to work in studying the atmosphere.

After half a dozen years of exploring the upper atmosphere with rockets, a number of things have been done which it was not previously possible to do. For example, the rocket enabled one to observe the sun's spectrum to below 2,000 Ångstroms, which is roughly a thousand Ångstroms below the limit of observation on the ground, and in the course of future investigations, the rocket will make it possible to observe the sun's radiation in detail at still shorter wavelengths. In the meantime, photosensitive materials and photon counters have been successful in detecting solar X-rays and far ultraviolet radiation in a number of rather broad wavelength bands. From the rocket ultraviolet spectrograms it has been possible to determine the distribution of ozone with altitude up to 70 kilometres height, well above the regions observable from the ground or from balloons. Also, with rockets, the pressure, temperature, and density of the upper atmosphere has been determined to great altitudes. On one flight the density at 219 kilometres was observed to be within 20 per cent. of 10^{-7} grams per cubic metre.

Ion and electron densities have been measured in the ionosphere. With the rocket it has been possible to determine such charge densities in the levels immediately above ionization maxima; such levels are not observable from the ground. By means of magnetometer experiments performed in Aerobees fired at the geomagnetic equator in the Pacific Ocean, it has been shown that at times there are current sheets in the E-region of the ionosphere. Such current sheets have been postulated to explain the daily variation in the magnetic field at the ground. High altitude winds have been observed and measured in rocket experiments, and during the flight of a Viking at White Sands, a wind of 80 metres per second was observed in the F-region of the ionosphere, at 200 kilometres.

The lower end of the cosmic ray spectrum, not observable from the ground or in balloons, has been studied at rocket altitudes. Preliminary results indicate the possible absence of low energy particles in the primary cosmic radiation.

There are many important questions concerning the upper atmosphere which still remain unanswered, and for which the rocket seems at present the best, or even the only, means for obtaining definitive answers. Following are a few examples:

(*a*) It is desirable to obtain the spectrum of the sun in the short wavelength region not yet observed in detail. Since the wavelengths concerned are cut off before reaching the ground, or even balloon altitudes, it will be necessary to send

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recording equipment aloft in rockets into and above the absorbing layers. Some of the radiations are involved in the formation of the F-regions of the ionosphere, and for their study the rockets will have to rise to several hundred kilometres.

(*b*) The chemical and physical make-up of the high atmosphere is fundamental to an understanding of what goes on there. Measurements should be made to determine the composition of the air, and its state of ionization, dissociation, and excitation. The matter of diffusive separation in the high atmosphere is yet to be settled. To carry such studies into the F-region of the ionosphere again will require rockets which can rise to several hundred kilometres.

(*c*) The various particles which impinge upon the upper atmosphere should be studied at first hand. Since many of them are stopped at high altitude, this will involve sending equipment up in rockets. Among those particles which are of interest are those involved in auroral activity, the low energy end of the primary cosmic-ray spectrum, and micrometeorites.

(*d*) The molecules of air in the high atmosphere continually emit what is called an airglow. This radiation is associated with the various photochemical processes going on there. Up to the present, however, there has been great disagreement as to the heights from which the different radiations come. It appears that the only way to settle the matter is to use rockets to pin down the levels at which the different wavelengths originate. Some of the estimated heights correspond to the F-region, and it may be necessary to send recording equipment to several hundred kilometre altitudes before the final answers are obtained.

(*e*) Finally, upper air densities, pressures, temperatures, and winds are fundamental parameters in the study of the atmosphere, and should be measured to as high as possible, and as often as possible.

STRUCTURAL PROBLEMS OF THE LUNAR BASE

By P. L. Sowerby, Assoc. M.C.T.

(*A paper read to the N.W. Branch in Manchester on February* 21, 1953)

SUMMARY

The choice of site and surveying in relation to lunar conditions is considered. The use of lunar materials, the possibility of making cement from lunar minerals, and uses of concrete on the Moon are also dealt with. Thermal protection is necessary. Pressure domes may be constructed of glass fibre cloth, with a maximum practical size of 100 ft. diameter hemisphere, weighing about 9 tons. It is concluded that the lunar base will be almost entirely underground, any surface pressurized works being of glass cloth.

Introduction

The problems of constructing a lunar base fall roughly into two classes:—

(*a*) The design of structures which would withstand lunar conditions.

(*b*) Obtaining suitable construction materials.

Although the latter point will obviously influence the choice of later sites, our knowledge of lunar mineral resources when the first base is established is

unlikely to allow us to determine a site on this basis, and other considerations must control the decision.

Surveying

Borings and tests of the chosen site must be made to determine not only the potential value of its component materials, but also its behaviour under the various loadings which may be placed upon it—a matter of even greater importance than on Earth.

The theodolites and tacheometers utilized in obtaining angles, levels and dimensions of the site (though the smallest dimensions will still be obtained by measuring tape as on Earth) will have to be different from those on Earth as the lunar surveyor has to wear a space suit. The object lens and cross hairs will probably be housed in a shielding tube on the levelling tripod, while the eyepieces, fitted with adjustable antiglare diaphragms, will be situated in the observer's helmet. In addition, the levelling staff will have to be self-illuminating, for use in shadow.

Lunar Conditions

The special conditions for which we shall have to design are:—

(i) A reduced gravity.
(ii) An inappreciable atmosphere.
(iii) An extremely wide temperature range.

The first involves merely the reduction of all static loading to one-sixth of its terrestrial value. Thus, less material will be required to carry a given load, and will therefore be easier to handle and place.

The second consideration is far more critical. If pressurized compartments are not built as units independent of the lunar surface—undesirable on several counts—they will have to be anchored sufficiently to counter an uplift of hundreds of tons due to internal air pressure. Even a tiny "tent," providing cramped quarters for one man, possesses an uplift of fifty tons (assuming 10 p.s.i. air pressure in a 10 ft. diameter hemisphere).

On the other hand, structures will not be subjected to the horizontal loads due to the winds which occur on Earth.

The wide temperature variations, in the region of 200° C., affect not only the properties of materials, but cause a correspondingly greater thermal expansion and contraction. This latter point is not in itself harmful, but if any constraint is present, either from the conjunction of two materials of differing coefficients of thermal expansion, or the presence of rigid joints in a ground anchored structure with continuous members, the stresses due to the bending moments induced at the joints will be correspondingly greater than those experienced on Earth.

Materials

The choice of materials for construction will largely determine the mode of design and the scope which the engineer will have in deciding the extent and layout of the base.

The most obvious materials are those which compose the Moon itself as they have the outstanding advantage of not requiring transport from Earth! The simplest way of utilizing them is to employ natural formations, e.g., caves or volcanic shafts and fitting them with airlocks, internal floors and partitions.

Alternatively, if no suitable natural formations are available, artificial tunnels may be formed by means of explosive and manual excavation—a simple method requiring no bulky heavy plant to be transported from Earth. A suitable site of commencement for these is a formation known as the "Straight Wall," a giant fault, about 500 ft. high, and sixty miles long, situated about 300 miles north of Tycho. This is suggested because—

(i) We would obtain a view of a 500 ft. section of the lunar crust without boring, and

(ii) Having checked the gradient of the plateau above the escarpment we can run our tunnels continuously for many miles if desired, approximately in a level plane, thus obviating the necessity for vertical shafts and consequent lifting gear, which would be required in other circumstances.

Our internal air pressures can be utilized to good effect in our tunnels. Since (assuming again, as throughout, a reduced pressure of 10 p.s.i.) the upward pressure of 1,440 lb. per sq. ft. will be countered solely by the weight of rock above it and we may dispense with pit props if the depth of the tunnel is varied according to the density of the material above it. The tunnel should be driven at a slightly shallower depth than is strictly required, reliance being placed upon the shear strength of the rock to prevent the roof blowing off! Allowing for the reduction of weight on the Moon, the approximate depth of a tunnel in material of similar density to granite, sandstone, etc. (about 150 lb. per cu. ft. on Earth) is in the region of 50 or 60 ft. However, cement plastering may be required also where the material is so porous that the air can penetrate and force particles off the roof.

Lunar materials may be used in several ways, viz.:—

(i) As aggregate for use with cement in the production of concrete if small enough (i.e., naturally, or by blasting and crushing larger rocks).

(ii) As rubble walling for internal partitions and occasional external works.

(iii) The largest rocks may be cut to shape for special uses, e.g., doorway lintels or floor beams.

Concrete

It is possible that cement may be produced on the Moon. Basically cement is quicklime (CaO) and clay (a hydrated silicate of alumina—$Al_2O_3.2Si O_2.2H_2O$). These oxides are to be found in the minerals horneblende ($5CaO.6SiO_2$), occuring in some forms of granite, and anorthite felspar ($CaO.Al_2O_3.2SiO_2$) occurring in both granite and basalt. If we assume, as seems reasonable, that the lunar equivalent of the Lithosphere, at least, is composed of the two primary rocks, basalt and granite, and the results of their erosion by violent temperature change and solar bombardment only, our only sources of materials for the production of cement will be horneblende and felspar.

Lunar cement, then, depends upon these factors:—

(i) The availability and proportions of the above minerals in the lunar rocks.
(ii) The ease or otherwise of their extraction and decomposition.
(iii) The amount of water available.
(iv) The amount of heat available for the final sintering process which reduces the ingredients to cement.

The action of solar heat may have already disintegrated the rocks into simple metallic oxides, and also thermally eroded them to such an extent as to obviate the necessity of grinding them down and the problem, if capable of solution at all, may prove simpler than is immediately obvious.

This leads us to consider the uses of concrete on the Moon, whether made either from lunar cement or transported from Earth. Though indispensable for many secondary purposes, it is grossly unsuitable for the pressurized buildings of the base. If, for example, we consider a hemispherical hut of internal radius 10 ft., and assume a mass concrete structure, anchored by its own weight, the shell would be approximately 11·6 ft. in thickness, which is patently ridiculous. Even ordinary reinforced concrete is uneconomic; the steel required is roughly $\frac{1}{4}$ in. diameter bars at $1\frac{1}{4}$ in. centres throughout. Putting a shell of concrete 3 in. thick around this requires 6 cu. yd. of concrete, which, utilizing lunar aggregate with terrestrial cement and water in a mix of 1 : 3 : 6 requires one ton of cement and half a ton of water. Since the steel weighs about five tons, a total of six and a half tons of material must be shipped from Earth. In addition, considerable workmanship would be required to the steel. Prestressed concrete has similar difficulties connected with its use.

Concrete will best be employed in precast beams, floorings, power and ropeway pylons—all preferably prestressed—and in consolidating poor ground, or grouting foundation bolts. The shuttering to be used could be of the sheet metal type, supported on small angles, and designed for lightness and for the lesser lunar loading. Possibly the metal will be superseded by plastics.

Vacuum Concrete

The present technique known as "vacuum concrete," whereby, with the aid of a vacuum pump, the pressure of the atmosphere is utilized in the consolidation of the concrete, will probably be applied exclusively on the Moon. The pump would be superfluous, since the difference between internal and external pressures could be used. Apart from the increased strength imparted, the greater resistance to the effects of frost, especially when air is entrained in the concrete, make it desirable. Repeated frost action reduces the value of "E," the modulus of elasticity: in ordinary concrete a reduction of 35 per cent. occurs after fifteen frosts, which equals a year and a quarter on the Moon, but with entrained air, vacuum concrete suffers the same reduction in over thirty years. The reduction of E is not dangerous, but the deflexion of a structure increases proportionately as E decreases, and eventually, when the deflexion becomes too great for the structure to fulfil the purpose for which it was intended, it must be discarded.

Since a reduction of 30 per cent. in the value of E also occurs when concrete rises to a temperature of 100° C., which will happen during the lunar day, it will be necessary to provide thermal protection, probably a silver or aluminium paint. As this will not be 100 per cent. efficient, the deflexions of a structure will still vary through the lunation, but to a lesser extent. Nevertheless, these variations must be accommodated. This protection would be required also for the sake of the personnel in the domes, and to guard against the effects of thermal expansion and the fluctuation in physical properties due to extremes of temperature.

Pressure Domes

The pressure domes, the most important part of the base, could be constructed of steel sheeting, silver-plated and polished, and welded up on the Moon. A 20-ft. diameter hut would require sheet about ·03 in. thick; however the thickness increases in direct ratio to the radius of the dome.

Other materials of lighter weight may be used instead of steel. The best of these is glass filament approximately one-third the weight of steel, yet nearly twice as strong, the strength increasing inversely as the diameter of the thread. This strength is reduced after weaving, however, presumably owing to the additional side loads imposed by the transverse threads, but a stress of 40,000 lb. per sq. in. is still reasonable, provided that the individual layer of cloth (continuous filament) is less than ·01 in. in thickness.

A dome 100 ft. in diameter would require layers of glass cloth to a thickness of ·075 in., rendered air-tight by spraying with a sealing compound inside, and either silver sprayed or merely polished, on the outside. The weight would be in the region of eight or nine tons, but the glass cloth could be transported layer by layer. This is likely to be a limiting size, however, for since a 200-ft. dome would weigh 53 tons, several smaller domes would obviously be more practical. Variations from a hemispherical shape in order to enclose a larger area with the same area of material is false economy, since, apart from the unequal stress distribution, much greater stresses are involved in a flat dome.

The coefficient of thermal expansion of glass is very little less than that of steel, and it may prove necessary to provide some means of preventing the movements of the dome rocking the securing bolts, thus loosing their hold in the concrete. Glass is, however, a very tough material, with great resistance to heat, and will probably withstand the extremes of the lunar night and day successfully.

Conclusion

It will be seen that the possibility of extensive surface construction, as portrayed frequently in imaginative drawings, is exceedingly remote. Surface domes will be kept to a minimum in both size and number, not only because they may require many terrestrial materials, but also in view of the extreme difficulty in anchoring them satisfactorily.

However, there are no limits to the extent of an underground base, other than those imposed by the excavating equipment available, and the depth requirements to balance air pressure with weight of rock. The ultimate "lunar city" will almost certainly be underground.

VISIT TO JODRELL BANK

Reported by C. A. Cross, M.A.

On June 20 a party of B.I.S. members and friends visited the Experimental Station at Jodrell Bank by courtesy of the Director, Dr. A. C. Lovell. The party was met by Mr. R. C. Jennison who first gave a short introduction to the work being carried on.

He began by mentioning the principles of radar, in which the reflection of a pulsed radio beam by an astronomical object is detected and analysed. This method is applied to the observation of meteors, where the reflection is obtained from the column of ionized gas produced as the meteor evaporates on entering the Earth's atmosphere. Mr. Jennison explained the use of directional beams to determine meteor radiants, the methods of determining meteor velocities, and meteor recording and counting techniques. This work had led to the detection of the intense daylight meteor streams, i.e., those with radiants so close to the Sun that they can never be seen against a dark sky. Measurements of velocities had also shown that all the meteors observed were members of the Solar System. Work on the reflection of radar pulses from the Moon was also carried on at the station.

Turning to the reception of radio signals originating outside the Earth, Mr. Jennison recalled the observations of Jansky in 1932, and later of Reber. These Americans proved that radio noise was received which had its origin in interstellar space. Surveys of the distribution showed in 1945 that the radiation was most intense in the plane of the Milky Way. In 1948 came the discovery of the "radio stars"—intense localized sources, whose position did not correspond with any bright visual stars. Since then the major development has been the improvement in resolving power of radio telescopes, culminating in the highly developed radio interferometers which have shown that some of the hundreds of radio stars now known are relatively extended areas by comparison with the visual stars. These radio "stars" have now been identified with three quite different types of visual objects:—

(*a*) *Extragalactic Nebulae.* These form rather faint and diffused "radio stars", showing that they contain radio sources like our own galaxy.

(*b*) *Gaseous Nebulae.* These are extended volumes of hot gas at extremely low pressure inside our own galaxy. At least one, the Crab Nebula, is known to be the remains of a supernova star explosion. Others are rather more mysterious and cannot be satisfactorily explained at present.

(*c*) *Extragalactic Nebulae in collision.* These collisions are not surprising, because the galaxies are large objects relatively close together. In such collisions the stars of each galaxy interpenetrate, pass through the collision area, and carry on unaffected. The clouds of interstellar gas and dust do, however, actually collide, and are left behind in the collision area. The energy of their relative motion has been converted into heat and ionization, and it is thought to be this large body of hot diffused gas which radiates.

Finally Mr. Jennison referred to the work on the hydrogen emission line. This line was due to the electron spin quantum, and could be observed in neutral hydrogen only when the particles had an extremely long period

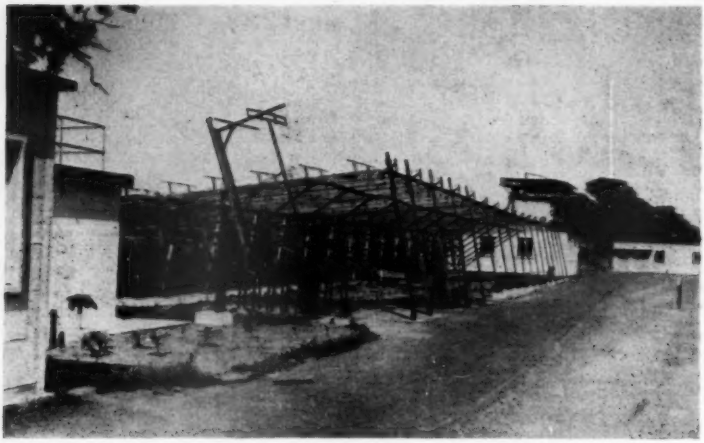


FIG. 1. Part of the aerial system working on the interferometer principle and used for the measurement of the diameters of radio "stars."

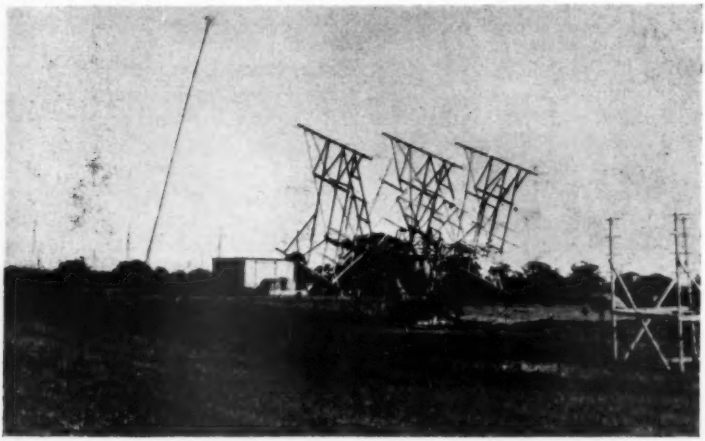


FIG. 2. An early aerial system erected on a searchlight mounting and used for the study of meteors.

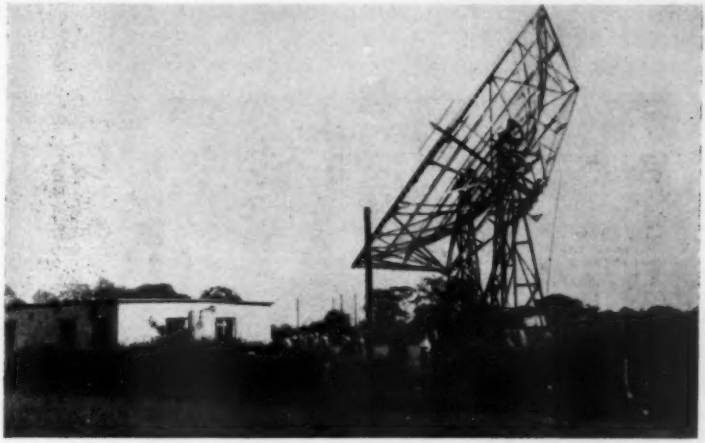


FIG. 3. The 30 ft. rotatable paraboloid now being modified to be operated electrically, and used at the time of the visit in a search for hydrogen lines in the radio spectrum.

between collisions. These conditions were met in the interstellar gas, and this emission line had been used to plot the gas distribution in our own galaxy. The results showed the spiral arms, and allowed us to deduce their direction of revolution.

On the site the various experiments are housed in huts on the perimeter of an expansive lawn. The lawn is a functional part of the establishment, forming a plane reflecting surface for some of the aerial arrays. The site is dominated by the fixed horizontal 200 ft. parabola, and the mast carrying the dipole at its focus. At the opposite side, a field away, lie the foundations for the giant steerable parabola. When erected this will tower more than 200 ft. above the surrounding countryside.

Adjoining the lecture room was a meterological station and general laboratory. In the next hut the party saw the radio interferometer. At the time the second aerial of the interferometer pair was 5 miles away. This gave the resolution needed to measure the diameters of the radio stars.

The "Polarization Hut" housed the arrangement of filters, amplifiers, and recorders used in conjunction with the 20-ft. steerable parabola for the work on the hydrogen emission line. The apparatus was currently in use searching for another line which had been predicted for ionized hydrogen. Here also was a model demonstrating the effect of solar flares on terrestrial radio transmission. One member of the party detected the steerable parabola swaying visibly in the breeze. He was reassured to learn that the beam width in use was several degrees! This parabola is mounted alt-azimuthally, but a control system is being installed to enable it to follow like an equatorially mounted array.

After the tour the party had tea in the adjoining Agricultural Station where a vote of thanks was passed unanimously to Mr. Jennison for his excellent job of exposition.

Later in the evening many of the party had dinner together at the Millbank Hotel and later visited the Godlee Observatory, though clouds prevented any observations.

AN INTERPLANETARY ENCYCLOPAEDIA

Reviewed by H. E. Ross

The *Encyclopaedia of the World's Aircraft and Astronautics*, compiled and edited by William E. Appleby, F.R.S.A., is the largest private collection of Aero-Astronautical Press cuttings and photographs in the world. Commenced in 1910, it embraces over 700 years of flying history and now amounts to some 4,300 loose-leaf volumes. Through the kindness of Mr. Appleby we have had opportunity to peruse well over half a hundredweight out of the total of six tons of material available. Life being short, we chose volumes of "interplanetary" interest; however, even so, the extracts cover a wide field—anything in fact from Morghen's Raccolta of 1810 to the spaceships, guided missiles, Flying Saucers, radio-telescopes and astronautical toys and games of modern times.

Perhaps the most striking thing about astronautical history is the thoroughness with which the great pioneers, such as Ziolkowsky and Oberth (both of whom were schoolmasters), probed and exploited the theoretical possibilities in every department of interplanetary art from celestial mechanics to rocketry. Practically all modern developments stem from their conceptions, and it is particularly noteworthy that both V2 and the A9/A10 combination are realizations of ideas advanced by Oberth as far back as 1922. However, the principle of the step rocket itself is attributed by one cutting to a French officer, Montgéry, in 1827. We also observe that a serious attempt at a liquid fuel rocket motor was made between 1895–97 by the Peruvian engineer Pedro Paulet, whilst in 1830 (believe it or not!) the Frenchman Claude Ruggieri sent up live rats in rockets, the animals being returned by parachute "or some gyroplane arrangement with blades extending after exhaustion of the fuel." Learning this, one is almost convinced that Morghen's Raccolta, which was a winged and manifestly sub-sonic chicken house, actually *did* land on the Moon!

Reaction-propulsion missiles and high-altitude rockets naturally occupy several volumes of the Encyclopaedia, and readers of this *Journal* will be familiar with most of them. The earliest reference we came across was to the Lorin pulse-jet flying bomb of 1910–11, but this was powered by a piston engine giving a jet exhaust. The pulse-duct motor actually used in V1, with its unique flap-valve mechanism, was invented by the Munich engineer, P. Schmidt, who in 1930 patented what later became known as the Argus-Schmidt "Schubroehre." However, the Doodle-Bug itself can be credited (if that is the right word) to Robert Lusser, an aeronautical engineer of the Fieseler Aircraft Works.

Pre-war B.I.S. Members will recall that Grindell-Matthews tried to interest the Government in schemes for anti-aircraft rockets and that he discussed his

projects with the B.I.S. Council and Technical Committee of that time. Something of this story has been related in two earlier *Journals*. Grindell-Matthews did not succeed in securing support for his ideas; however, it is now apparent that officialdom was not quite so inattentive as it made itself out to be. Perhaps it was an instance of the wrong person rocking the boat. Be that as it may, it is to be noted that one project proposed by G-M was actually used, though in a comparatively minor role, for in the encyclopaedia we find cuttings from *Flight* of August 20, 1942, showing the firing of a rocket which trailed a wire and descended slowly by parachute, the device being intended for defence against dive-bombers.

Scanning more volumes we see that ideas which in 1930 were laughed at as sheer fantasy have now been surpassed, for giant rockets have become fact and spaceships are treated as serious propositions. However, clearly a great deal remains to be done before it is possible to say "this, then, is a moonship." Indeed, like all other transport, spaceships will differ according to the job they have to do. For example, a rocket designed to return into the Earth's atmosphere may well be winged but not so the vehicle that has to land on the airless Moon. Modern conceptions (at least those based on scientific assessments) are more appreciative of practical requirements than those of earlier date but mostly still fall between the two stools of over-simplification and over-elaboration. Evidently what is wanted is a little more science and a lot more common sense.

The extent to which astronautics has captured public imagination is well illustrated by numerous cuttings. Nearly everything, it seems, has "gone interplanetary." Theology—mysticism—*Old Moore's Almanack*—advertising—films—fashions—children's toys, games, stories and comics—stage magicians—fun-fairs—cartoons—all these now have an "interplanetary angle" and so find their way into this encyclopaedia. Small wonder that many people cannot understand where the serious side of astronautics ends and the fooling starts!

Maybe it begins round about the level of Flying Saucers, which are well documented in two volumes of the encyclopaedia. According to *Look* of July 1, 1952, the U.S. Air Force had collected more than 800 sightings up to that date. *Look* adds "They . . . found that 38 per cent. could be classified as astronomical bodies, 13 per cent. as balloons, 10 per cent. as too nebulous to be valuable, 22 per cent. as birds and aircraft, etc., 2 per cent. as hoaxes and 15 per cent. as 'unexplained'."

The trouble is of course that so long as only *one* Flying Saucer remains unidentified, that in the opinion of many people will be IT—the real one that got away. In the meantime astronauts, whatever their private views, should at least be grateful for the amount of free publicity that Flying Saucers are providing. Perhaps one of the next 30 volumes or so of this encyclopaedia will settle the question of Flying Saucers to everyone's complete satisfaction. . . . More probably the Artificial Satellite project will have become fact.

BOOKS AND PERIODICALS on astronautics bought and sold—G. V. E. Thompson, 31, Brooklands Gardens, Hornchurch, Essex.

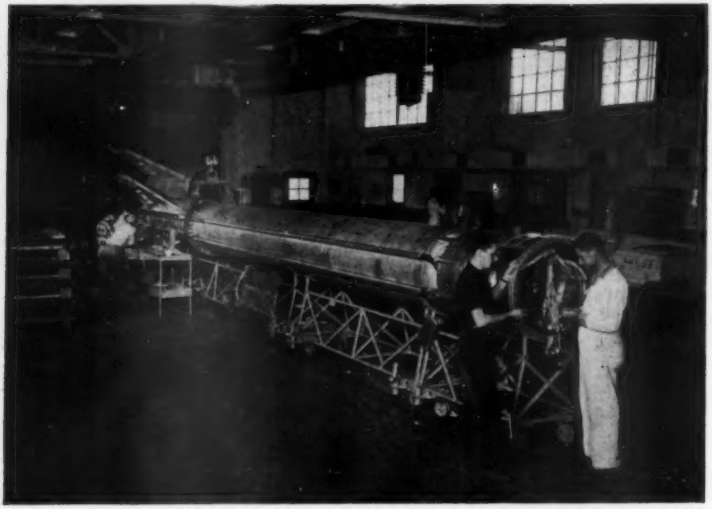


FIG. 1. Arriving at White Sands, the Viking goes into a hangar when the check-outs begin, catching trouble that may have been caused by the long railroad trip from Baltimore. Two technicians are seen examining the forward wiring.

FIG. 2. Checking the electrical system of the power plant.

NOTES AND NEWS

1954 Annual Subscriptions

The 1954 Annual Subscriptions fell due on January 1 and Members are asked to remit as soon as possible.

The rates payable are as follows:—
Fellowship, £2 12s. 6d. ($7.50); Membership, £1 11s. 6d. ($4.50); Members under the age of 21 years, £1 1s. 0d. ($3.00).

Those Members having bank accounts would undoubtedly find it of great assistance to complete and send to their bank the Society's special Banker's Order form, as this would ensure that future subscriptions are paid automatically on the due date, and subsequent reminders may be ignored.

This arrangement is also of considerable benefit to the Society, as it leads to a substantial saving in time and expense.

Those Members who are able to do so may wish to consider the question of compounding future annual subscriptions by payment of a single lump sum, in accordance with the scale which appeared on page 301 of the November, 1953, *Journal*.

The Viking Rocket

The accompanying four photographs illustrate various stages in the launching of a Viking high-altitude research rocket, built for the Naval Research Laboratory by the Glenn L. Martin Company.

The rocket motor, developed by Reaction Motors, Inc., develops 20,000 lb. of thrust, the propellants are liquid oxygen and alcohol, and the complete vehicle costs about $400,000—according to the latest figures. An all-aluminium construction enables the take-off weight to include 80% propellants, quite an improvement over 67% for the V2, and 55% for the Aerobee.

Nine Vikings have been launched up to January 1, 1953, but only four of these can be regarded as normal flights, reaching an average altitude of 121 miles. The average altitude of all flights is 73 miles and the highest altitude attained is 136 miles. The missile is still under development and it is hoped eventually to reach 200 miles altitude.

The Viking is thoroughly checked before it leaves the factory at Baltimore and is again checked after the long rail journey to White Sands Proving Grounds. The vehicle is then moved to the launching site and erected in the gantry in preparation for a static test of the power plant. For this the rocket is bolted to the launching platform and the flame goes into a pit filled with water.

When the motor has been found to function correctly the instrumented nose cone is assembled and checked. Electronic and other equipment picks up important information during the flight. Data on altitude, speed, temperature, cosmic ray counts, etc., are telemetered back to earth and permanently recorded for future study.

The last few hours before the launching are crowded with final preparations. Each aspect of the programme—missile loading with propellants, assembly and preparation of instrumentation, range readying—has to coincide with that

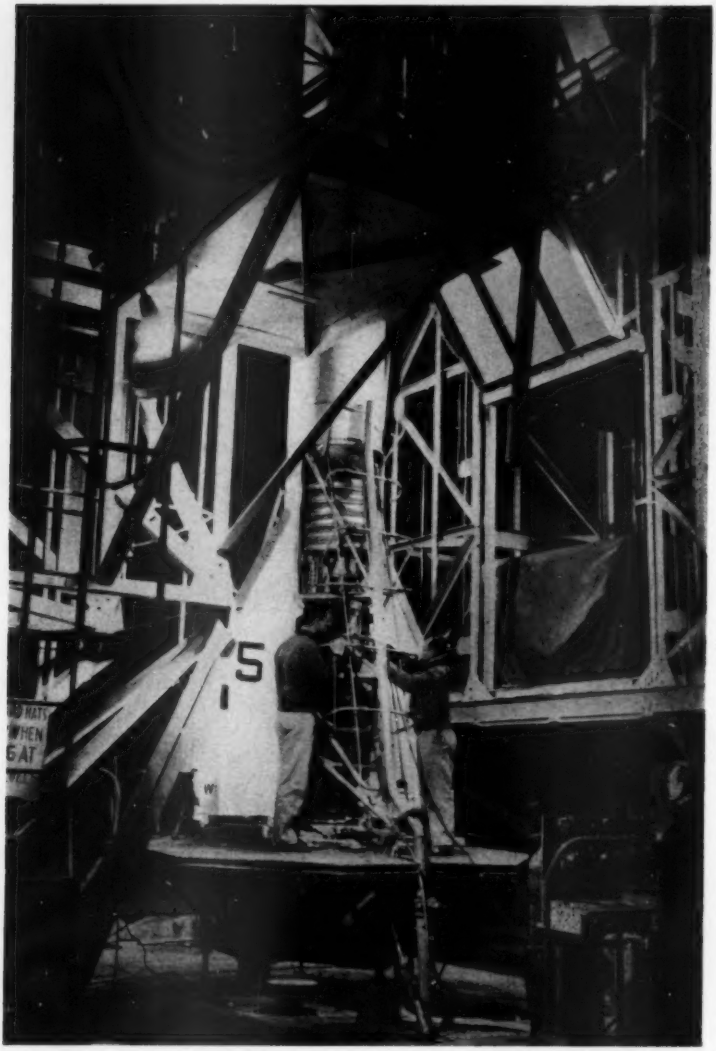


FIG. 3. Work on the Viking sometimes has to continue all night, when an early morning launching is scheduled. Two technicians work on the missile while another stands by the portable gauge panel (*right foreground*).

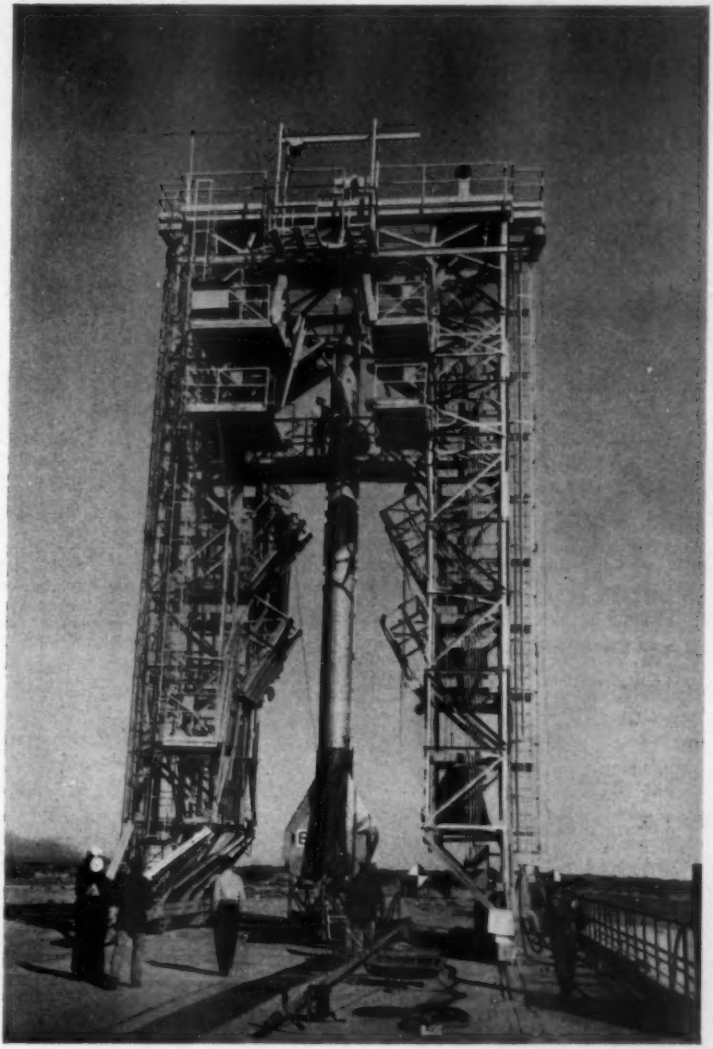
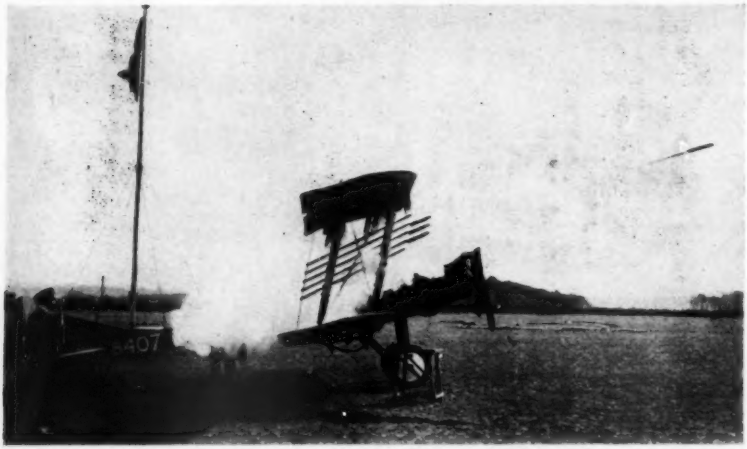


FIG. 4. The Viking stands ready in the gantry. Soon it will be filled with propellants and ready for firing. Final preparations for launching are made from the working platforms on a movable gantry which surrounds the rocket.

An early Armstrong-Whitworth test vehicle. The auxilliary booster rockets which help the main unit to accelerate to supersonic speed, can be clearly seen in a band round the main vehicle



Experimenting with Le Prieur rockets which were used for destroying kite balloons or airships. They were attached to the struts of the aircraft, and fired electrically. Their best range was under 400 ft. (*Compare with photograph of Lockheed Starfire firing rockets on page* **236**, *September*, **1953**, "*Journal.*")

vital moment, launching time. There is no time for delays and all personnel have to work at top pressure to ensure that the launching schedule progresses smoothly.

The time from depressing the launching button until the Viking itself disappears from view is less than a minute. Often there is a vapour trial in the stratosphere to show where the rocket has passed. During the flight, the rocket is tracked by optical tracking telescopes and the DOVAP radio system.

Then follows the recovery operation. Search parties in light planes, helicopters, trucks and jeeps search the New Mexico sands for the remains. As the rocket has broken up in its descent through the denser regions of the atmosphere, the parts fall at comparatively low speeds. But the flight and the recovery marks only the beginning. Afterwards follows many months of sifting and analysing the data which the rocket has gathered, and upon the accurate and correct interpretation of this data depends the success or otherwise of the experiment.

1953 S.B.A.C. Show

Several rocket exhibits were displayed at the 1953 S.B.A.C. Show at Farnborough.

The Ministry of Supply stand included two solid propellant rocket motors, the "Ladybird" and "Scarab", designed and developed at Westcott for the assisted take-off of aircraft.

"Scarab" produces a mean thrust of 3,000 lb. for approximately six seconds, giving a total impulse of 20,000 lb.-sec., and "Ladybird" produces a mean thrust of 1,500 lb. for approximately six seconds, giving a total impulse of 10,000 lb.-sec.

Each motor contains a cordite charge in a 45-ton steel case. These steel cases are produced by special processes by the Chesterfield Tube Co., Ltd., of Chesterfield and British Messier, Ltd., of Gloucester. The former company use their cold drawn process, while the latter use fabrication of sheet steel welded by automatic processes which they have developed.

The total weight of a filled "Scarab" motor is 175 lb. and the filled "Ladybird" motor 100 lb.

The De Havilland stand contained a "Super Sprite" unit, described on page 290 of the November, 1953, *Journal*, and the Armstrong Siddeley Motors stand included a "Snarler" rocket motor.

Fairey Aviation showed an early solid rocket, and photographs of the "Stooge" and V.T.O. units.

A photograph of an "early Armstrong Whitworth guided missile," also in the show, is reproduced opposite.

Armstrong Whitworth is a member Company of the Hawker Siddeley Group, and in addition to conducting work on guided missiles in this country, also has a factory unit at Woomera, in Australia.

From the World's News

"After Everest, what next in this Elizabethan Age?" was the theme of several Press articles which appeared during July. Prominent among the prophecies

FAIREY V.T.O.

One of the series of Fairey Vertical Take-off delta-wing, rocket-powered models tested at the Woomera Range, Australia. It is powered by a Fairey-developed Beta rocket-motor, which has two 900-lb. thrust jets. Two 600-lb. solid-fuel booster rockets are also used during initial stages of launching.

The Woomera tests, made under contract from the Ministry of Supply, explored the practicability of launching aircraft from short ramps at low accelerations, and included test launches in near-vertical climbs.

was the imminence of space-flight, with the Moon, some 42,000 times "higher" than Everest, cited as an early objective. Most of the articles contained well-informed summaries of the problems and present-day ideas for overcoming them but tended to overrate the claims which space-voyaging will make upon human endurance. Actually, in this respect, no similarity exists between the conquest of Everest and the conquest of space. For whereas the ascent of Everest was made, and intentionally made, with a *minimum* of scientific aid, the conquest of space will employ *maximum* scientific aid. The reason for this is that whilst Everest was a challenge to human endurance, astronautics presents a challenge to human ingenuity. There is indeed no point in adding to the dangers of space by taxing human endurance. On the contrary, avoidance of physical stress must be the aim. There is certainly no need to employ dangerously high accelerations, for that is simply a matter of technical control, obtainable at the expense of some efficiency. Even the foreseeable discomfort attending conditions of no-gravity can at most times be avoided by rotating the ship. And extremes of temperature can fairly easily be safeguarded against by elaborations of well-known thermal insulating techniques. As for maintaining an adequate supply of fresh air, that too is a problem offering no insuperable difficulties.

One of the most graphic visualisations of interplanetary voyaging was provided by Robert Chapman, with illustrations by Edgar Spenceley. It consisted of a series of nine articles, with a tenth by our Secretary, Mr. L. J. Carter. Beginning by discriminating between science fiction and astronautics, the author took his readers on a trip to the Moon, and then on to Mars. The ninth article dealt in a sensible and factual way with "Flying Saucers." Mr. Carter's contribution included a short history of the B.I.S., together with current activities, and summarized trends in astronautical thinking. This series appeared in July printings of the London, Glasgow, and Manchester *Evening News*, the Middlesbrough *Evening Gazette*, the *South Wales Echo*, and in the Newcastle *Evening Chronicle*, where it was preceded by an introductory article by Eric Burgess.

* * * *

Everyone knows that when *Picture Post* goes to town it does so in a big way. Certainly the three-issue interplanetary series by science writer Egon Larsen, entitled *My Journey into Space*, was no exception. Written as the experiences of a journalist on the first flight to the Moon, it was illustrated by no less than twenty fine R. A. Smith drawings.

* * * *

According to the *Scotsman* of July 11, two barbers and a butcher of Atlanta, Georgia, have tried to pass off a monkey as a man from outer space. The *Scotsman* rightly condemns this as a cruel and stupid hoax. Certainly in this country it would evoke violent action from the R.S.P.C.A., for this body officially condemned the American rocket experiments with live mice and monkeys—something which (in our opinion at least) is a necessary precursor to manned ventures. Better that animals should perish than that human

life should be needlessly endangered. Those who think otherwise should remember the countless human beings who have been saved as the result of knowledge gained through experiment with animals.

* * * *

Guy Waller, writing flippantly in the *Winnepeg Tribune* of July 10, thinks that the disposal of garbage from cruising spaceships may become a headache for U.N.O. Says he—"Fifty years from now, if you want to steer a rocket to the moon, you'll need no gadgets, only one piece of advice: Follow the empty cans."

Momentarily in the same light vein, we ourselves visualize the discovery of a third satellite of Mars—Spam!

* * * *

The operational use of guided missiles from U.S. ships will begin during next year, according to a B.U.P. news item in the *Glasgow Evening Citizen* of June 20.

Another cutting from the *Rhodesia Herald* of May 12 quotes a report from London which says that Switzerland has developed a 15-ft. beam-rider rocket (presumably the Oerlikon) that can be fired 12 miles up with complete precision to destroy enemy planes within a 15-mile radius of the rocket's base. The account adds that these rockets, each costing £5,000, will be tested in combat with remote-controlled aircraft.

The May issue of *Chemical Engineering* (N.Y.) gives some details of a rocket-propelled test sled designed and built by North American Aviation which achieves a speed of 1,500 m.p.h., using an oxygen-alcohol propellant combination and generating 50,000 lb. of thrust. It is said that the speed of 1,500 m.p.h. is realized in 4·5 sec., over a distance of 5,500 ft. The report adds: "The rocket engine will run up to 8 sec. with one fuelling, and refuelling is almost as easy as gassing up an automobile. The engine and sled are being used by the Air Force to test parachute designs for supersonic jet airplanes and to determine the effects of high speeds on humans."

* * * *

Getting one's name in the paper is no trouble to scientists these days—the trouble comes in getting it out again . . . .

Dr. Fritz Zwicky, for one, will no doubt agree with this remark, for he must have been annoyed by reports saying that he had obtained permission to use Woomera for some new man-made meteor experiments involving, it seems, the firing of small bullet-size objects from balloons 20 miles high. We regret if that is not a correct statement of Dr. Zwicky's project, but this is about all the sense we can extract from the exceedingly confused and (we suspect) very misleading accounts which have appeared.

Be that as it may, the reports provoked Australian Supply Minister, Mr. Howard Beale, into denying that he had given anyone permission to shoot projectiles from Woomera "to the Moon, Mars and other planets." According to the Dublin *Evening Herald* of August 17, Mr. Beale added: "I never heard of Dr. Zwicky, and it's news to me."

We trust that Mr. Beale has also been misquoted.

ABSTRACTS

Edited by J. HUMPHRIES

Abbreviations of titles of journals were given in the May, 1950, issue of the *Journal*, and addenda have appeared in subsequent issues. The following is a further addendum to the list.

Aust. J. Phys.	Australian Journal of Physics.
J. Opt. Soc. Amer.	Journal of the Optical Society of America.
J. Phys. Chem.	Journal of Physical Chemistry.
K. Fysiogr. Sällsk. Lund, Förhandl.	Kungliga Fysiografiska Sällskapets i Lund, Förhandlingar.
Selected Govt. Res. Repts.	Selected Government Research Reports.

Many of the articles noted are available on loan to members resident in the British Isles. Requests should be addressed to J. Humphries, 97, Churchill Avenue, Southcourt, Aylesbury, Bucks.

AIRCRAFT

(1) **Russians push rocket fighter program.** *Amer. Aviation*, **15**, 2-4 (*Nov.* 10, 1952).

ASTRONAUTICS

(2) **A collision path from the Earth to the Moon in the restricted problem of three bodies.** A. A. GOLDSTEIN and C.-E. FRÖBERG. *K. Fysiogr. Sällsk. Lund, Förhandl.*, **22** (14) (1952) (*in Swedish*). The trajectory of a projectile is computed for an initial speed of about 1·5 times escape velocity. The orbit of the Moon relative to the Earth is assumed to be circular.

(3) **Von Braun offers plan for station in space.** VON BRAUN. *Aviation Age*, **17**, 61-63 (*Dec.*, 1952).

(4) **Escape from Earth.** J. G. VAETH. *Flying*, **52**, 27-44 (*Dec.*, 1952).

(5) **On the fundamentals of astronautics.** G. A. CROCCO. *Aerotecnica*, **33**, 135-140 (*April*, 1953). (*In Italian*). General review. Proposes new method of step construction in which the stages are associated in parallel and can be recovered.

(6) **Astronautics.** A. EULA. *Aerotecnica*, **33**, 231-244 (*June*, 1953). (*In Italian.*) General review.

(7) **Space flight congress.** A. E. SLATER. *Aeroplane*, **85**, 230-231 (*Aug.* 21, 1953). Report on 4th International Astronautical Congress.

(8) **Are we nearer to space-flight?** E. BURGESS. *Flight*, **64**, 259 (*Aug.* 28, 1953). Report on 4th International Astronautical Congress.

ASTRONOMY

(9) **Visual and photographic observation of the planets Mercury and Venus.** A. DOLLFUS. *Astronomie*, **67**, 61-75 (*Feb.*, 1953). (*In French.*) Recent work, done mainly at the Pic du Midi Observatory.

(10) **Visual study of the surface of the planet Mars.** A. DOLLFUSS. *Astronomie*, **67**, 86-106 (*March*, 1953). (*In French.*) Recent studies made at the Pic du Midi, relevant to such problems as the Martian relief and the true nature of the "canals."

(11) **The surface temperature of the Moon.** J. C. JAEGAR. *Aust. J. Phys.*, **6**, 10-21 (*March*, 1953). Results of numerical calculations are given for (1) the fall in surface temperature during a lunar eclipse, (2) the variation in surface temperature at the equator during a lunation, and (3) the variation in microwave temperature at the equator during a lunation.

(12) **Rocket astronomy.** R. TOUSEY. *J. Opt. Soc. Amer.*, **43**, 245-251 (*April*, 1953). Reviews the results of studies of the solar spectrum made from rockets and extending from the ultra-violet to the soft X-rays.

(13) **The apparent south pole of Venus, with some notes on the inclination.** J. C. BARTLETT. *Strolling Astronomer*, **7**, 65-74 (*May*, 1953). Recent studies of the surface of Venus, with particular reference to the position of the "pole."

(14) **The changeable appearance of Jupiter's great red spot.** E. J. REESE. *Strolling Astronomer*, **7**, 88-93 (*June*, 1953). History of the red spot in recent years.

(15) **The rotation of the solid nucleus of Jupiter.** E. J. REESE. *J. Brit. Astr. Ass.*, **63**, 218-221 (*June*, 1953). Recent theoretical work based on observational evidence.

(16) **Recent observations of Venus.** P. MOORE. *J. Brit. Astr. Ass.*, **63**, 260-263 (*July*, 1953). Report on recent observations with special reference to the sharply-defined linear markings reported by various observers.

(17) **Intensity of Lyman-Alpha line in the solar spectrum.** W. A. RENSE. *Phys. Rev.*, **91**, 299-302 (*July* 15, 1953). The Lyman-Alpha line appeared on a rocket spectogram obtained by means of a grazing-incident spectograph pointed directly at the sun for a 28-second exposure. The rocket used was an Aerobee and the average altitude during exposure was 81 km. The Lyman-Alpha was the only line observed in the far ultra-violet. The total intensity outside the Earth's atmosphere is estimated to be 0·05 micro-watts per sq. cm.

(18) **The distance scale of the Universe.** O. STRUVE. *Sky and Telescope*, **12**, 238-242 (*July*, 1953). Concerning the recent discovery that the whole distance-scale of the Universe must be revised, and that the external galaxies are much more distant than has been previously believed.

(19) **General conditions at the Moon's surface.** D. ALTER. *Griffith Observer*, **17**, 86-92 (*Aug.*, 1953). General survey of lunar conditions.

ATMOSPHERE

(20) **Rocket exploration of the upper atmosphere.** E. BURGESS. *Engineer*, **196**, 302 (*Sept.* 4, 1953). Report on Oxford "Conference on Rocket Exploration of the Upper Atmosphere."

(21) **Rocket exploration of the upper atmosphere.** J. HUMPHRIES. *Engng.*, **176**, 360-361 (*Sept.* 18, 1953). Report on Oxford "Conference on Rocket Exploration of the Upper Atmosphere."

CHEMISTRY

(22) **Kinetics of the thermal decomposition of nitric acid vapor. II. Mechanism.** H. S. JOHNSTON, L. FOERING and R. J. THOMPSON. *J. Phys. Chem.*, **57**, 390-395 (*April*, 1953). Process has been followed in detail at 400° C. by optical analysis for both nitric acid and nitrogen dioxide. Reaction is more complex and rate faster than previously proposed. The fast initial rate is inhibited by nitrogen dioxide, unaffected by water and oxygen, and sustained by nitric oxide.

MATERIALS

(23) **Thermal stresses in non-ductile high-temperature materials.** F. J. BRADSHAW. *Selected Govt. Res. Repts.*, **10**, 71-84 (1952). Stresses are evaluated for simple shapes such as the infinite slab and cylinder and estimates made of practical stresses in turbine blades and rocket nozzles.

PHYSICS

(24) **Manometric determination of the density of liquid ozone.** C. BROWN and K. D. FRANSON. *J. Chem. Phys.*, **21**, 917-919 (*May*, 1953). Results for a sample >99·9 per cent. pure were 1·571 at −183° C., 1·595 at −188° C. and 1·614 at −195° C.

(25) **High-temperature combustion.** H. REICHERT. *Aircraft. Engng.*, **25**, 198-199, 212 (*July*, 1953). A new type of Mollier-chart for high-temperature gas mixtures at equilibrium. These enable a very wide range of conditions to be covered with relatively few charts and are particularly useful for rocket applications.

PROJECTILES

(26) **"One-shot" batteries perfect for guided missiles use.** *Chem. Engng. News*, **30**, 2393-2395 (*June* 9, 1952). Describes new zinc-silver peroxide system giving high power/weight ratio and other new systems.

(27) **Guided missiles blast off new Oerlikon arms program.** *Aviation Age*, **17**, 25-27 (*Dec.*, 1952).

(28) **Guided missiles.** A. AEPLI. *Flug. u. Tech.*, **15**, 136-140 (*June*, 1953). (*In German.*) Discusses stability problems, types of remote control and proximity fuses, giving as examples the German techniques of the last war. Also methods of launching, aerial warfare and sounding rockets.

(29) **Guided missiles: comments on surface-based antiaircraft missiles.** H. H. PORTER. *Aero. Engng. Rev.*, **12** (7), 24-29 (*July*, 1953). Choice of propulsion unit, various guidance systems, method of use and costs.

(30) **First closeups of Fairchild Lark.** *Aviation Wk.*, **59** (3), 39 (*July* 20, 1953). Photos and approximate specification.

(31) **Holloman tests missiles and pilotless aircraft.** *Aviation Wk.*, **59** (7), 186-188, 193-194, 196, 199-200, 204, 206, 209 (*Aug.* 17, 1953). Besides the normal missile firings—60 of which were scheduled for July, 1953—Holloman Air Development Center also houses a Space Biology Laboratory, one of whose main jobs is to determine the biological effects of primary cosmic radiation.

(32) **Missile center expands for long-range flights.** *Aviation Wk.*, **59** (7), 170-172, 175-176, 178, 181, 183-184 (*Aug.* 17, 1953). Describes Air Force Missile Test Centre, Point Mugu, U.S., and its facilities. Actual firings are rare, but it is hoped to initiate 500-mile missile firings this autumn.

ROCKET MOTORS

See also abs. no. 23.

(33) **Rockets.** *Nature*, **171**, 1006-1007 (*June* 6, 1953). Summaries of three papers delivered to the Society for Visiting Scientists.

(34) **D.H. Super Sprite.** *Flight*, **64**, 238 (*Aug.* 21, 1953). A development of the D.H. Sprite, using hydrogen peroxide decomposed by a solid catalyst plus injection of gasoline or kerosine. Maximum thrust 4,000 lb. (Sprite 5,000 lb.); duration 40 sec. (12 sec.); total impulse 120,600 lb. sec. (55,000 lb. sec.).

(35) **British aero-engines today.** *Aeroplane*, **85**, 375-390 (*Sept.* 11, 1953). Essentials of rocket motors and descriptions of British designs.

REVIEWS

The Moon.

(By George Gamow. Published by H. Schuman, New York, 1953. 118 pp. $2.50.)

This short book is divided into five chapters: "Chandrasekhar, Carrier of the Moon," which deals with generalities and the lunar phases; "The Moon, the Apple and Sir Isaac"; "Moon's Birth"; "Selenography"; and "Moon Express." There is also a long comic introductory poem by Edmond Rostand, and a number of humorous illustrations by Bunji Tagawa.

The book makes pleasant reading, and though it seems that the author does not mean some of it to be taken too seriously, some of the more obvious misprints and errors could well be tidied up. For instance, Galileo was not responsible for naming the lunar "seas"; where the dimensions of craters are given, they are frequently wrong (Archimedes, for instance, is said to have a diameter of 40 miles instead of 50); and mis-spellings are common. On page 80 we have "Autolychus" and the "Appennines," and on the map on page 81 there are some unusual names indeed—the Haemuses, Mare Nectarus, the Corthpatians (presumably the Carpathians) and even "Mare Australia," which can be identified by its position as the Mare Australe.

Chapter 5, which is the space-travel section, is taken up largely with quotations from Jules Verne and a description of the famous projectile of his "Gun Club," though it is fair to add that Dr. Gamow makes it clear at one point that the president of this Gun Club was "talking somewhat through his hat." Later in the chapter there is an account of a moon rocket planned by a Dr. U. Stan, and considered by Dr. Gamow as quite practicable: "The moon rocket is simply a long cylinder carrying a number of regular atomic bombs. The bombs are

pushed out one by one from the rear opening, and exploded at a certain distance behind the vehicle, which has a very broad flaring rear. Each explosion kicks the rocket forward, and Dr. Stan estimated that a dozen or two of such kicks would easily communicate to the rocket a speed which is enough to overcome the gravity of the Earth." It seems to the reviewer that there are certain objections to this idea!

In short, "The Moon" will provide its reader with an agreeable hour; but it is fair to add that it is not quite the sort of book we expect from so brilliant a writer and scientist as Dr. Gamow.

P. MOORE.

The Green and Red Planet

(By Hubertus Strughold. Published by the University of New Mexico Press. 107 pp. $4.)

In the absence of convincing evidence, any discussion about the possibility of life on another planet must be very speculative indeed. Dr. Strughold has attempted, however, to keep his speculation within the bounds of present day biological and physiological knowledge by combining that knowledge with what evidence there is concerning physical and climatic conditions on Mars.

Bearing in mind, therefore, all the facts that *are* known about Mars, such as composition and density of the atmosphere, temperature fluctuation, humidity, length of day, etc., he considers *known* biological systems which might operate successfully on Mars.

The above treatment means that the writer must ensure that the non-biological reader understands some of the relevant information on plant and animal physiology, and the book therefore devotes much of its space to elementary biology, although this is generally well blended in with the discussion.

The author concludes eventually that, assuming life on Mars evolved on similar lines to that on Earth, the only type of organisms that could survive would be lichens and bacteria. This is an eminently reasonable conclusion, based as it is on what we know of life on Earth. There is, however, no reason to suppose that enzymic and energy transfer systems need not have arisen on Mars fully adapted to the rigorous, by our standards, conditions on that planet, a prospect which would mean that very complex biological systems might indeed exist on the "red planet." This concept Dr. Strughold knowingly and wisely avoids as being of such extremely speculative nature that one can do no more than hint at its possibility.

Dr. Strughold's book is, in general, well presented and illustrated, the only faults being his frequent lapses into teleology and, fortunately fewer, metaphysics. For instance it is not scientifically justifiable, unless we assume we are in the confidence of the Maker in these matters, to say that, ". . . the object of the process (anabolism) . . . to create living substance . . . is for the purpose of being transformed into energy" (page 15). We *can* say, "anabolism creates living substance which is later broken down with the production of energy." This is not merely a quibble over words, it is something which strikes at the roots of scientific thought and it is a great pity that Dr. Strughold should have marred his book in this way.

Other minor points:—*Euglena* (page 14) should, of course, have the generic name spelt with a capital. The bacteria are not usually classified into the animal kingdom, but as there is nothing sacrosanct about biological classification, Dr. Strughold can please himself in this matter. It is difficult to understand the argument (page 72) about the advantage a plant has if water freezes in the intercellular spaces and not in the cells. Water in the cells contains solutes which will depress the freezing point below that of pure water; if the temperature falls below the freezing point of the cell solution this will solidify anyway, intercellular spaces or no. If, however, the temperature is not low enough to freeze the cell contents but low enough to freeze the transpired (and relatively pure) water in the intercellular spaces then it would seem that the spaces are a disadvantage, since damage to the surrounding cells by the growing ice crystals is almost bound to occur.

E. R. NYE.

Samolet-Raketa (Reaktivnaya Aviatsiy)

(By L. K. Baev and I. A. Merkulov. 64 pp. Gosudarstvennoe Izdatel'stvo Tekhniko-Teoreticheskoi Literatury, Moscow-Leningrad, U.S.S.R. 1952. 1 rouble.)

This booklet, which is No. 39 in the "Popular Science Library," is entitled *The Aeroplane-Rocket* (*Reaction Aviation*), but is concerned with both rocket- and jet-propelled aircraft. After discussing flight at high speeds and high altitudes, the principle of reaction and its application in the piston engine, turbine and rocket motor is explained. Then follows the inevitable chapter headed "The Priority Belongs to Russia." Inevitable, not because this is a Russian book, but because it deals with a modern invention. British, American and German writers have also concerned themselves with the futile question of priority; the gas turbine has been shown to be descended from Hero's aeolipile and the Elizabethan turnspits.

As it turns out, no sensational claim for priority is made; it appears that signal rockets were in use in the Russian army in the time of Peter the Great, whilst at the beginning of the nineteenth century General Zasyadko devised a military rocket. The work of the Russian pioneers Konstantinov, Kibal'chich, Tsiolkovskii, and F. A. Tsander is then outlined (the celebrated interchange of letters between Tsiolkovskii and Stalin is, of course, mentioned), but brief reference is also made to Goddard and Oberth. Your reviewer was surprised to learn that the "general theory of motion of bodies of variable masses was established by another eminent Russian scholar—Professor I. V. Meshcherskii."

Chapter V is devoted to the rocket motor—how it works, the propellant supply system, motors for rocket aeroplanes. The illustration of an aircraft rocket motor (un-named) and accompanying data appear to relate to the German Walter 109–509.

The remainder of the booklet is mainly concerned with the ram-jet, the gas turbine and their characteristics compared with those of the rocket motor, the design of supersonic aircraft and similar topics. It concludes by hinting at the future possibilities of an atomic rocket.

G. V. E. THOMPSON.

The Comets and their Origin

(By R. A. Lyttleton. Cambridge, at the University Press, 1953. Pp. x + 173, with 15 figs. and 13 plates. 25s. net.)

A bright comet may be a striking object, and the dynamical problems of cometary orbits have long occupied an important place in celestial mechanics. To astrophysics, however, comets have proved something of a Cinderella, mainly because of the difficulties of observation, and the even greater difficulties of the interpretation of the observations.

The first two chapters of Dr. Lyttleton's book, some third of the whole, are devoted to a summary of the observed properties of comets, both dynamical and physical. Within the limits set by space, these summaries are adequate, and include a number of the historical curiosities with which cometary literature abounds. These chapters are illustrated by photographs and earlier drawings of cometary structure. The next two chapters, which form the major part and major contribution of the book, are concerned with developing, in a form suitable for popular as well as technical consumption, the accretion theory of the origin of comets, of which theory the author and Mr. Hoyle have been the main architects and advocates. In brief, comets are supposed to originate in the capture of material by the sun in its passage through an interstellar cloud. The accretion mechanism was originally proposed as an important factor in the evolution of some stars; the formation of comets entered as a by-product. Here, the accretion process is analysed with reference to the formation of comets, and not the general problem of stellar evolution.

On this theory, a comet is seen as an aggregate of particles pursuing more or less independent orbits around the sun. Attempts are made wherever possible to correlate the predictions of the theory with the observed properties of comets. It is no demerit of the theory, but rather a reflection on the difficulties of obtaining physical data on comets from observation, to say that these correlations are in many cases less than satisfactory. Thus the theory predicts changes in the size of comets near perihelion; such changes are not in general shown by the *observed* sizes, but, as is correctly pointed out on page 130, the observed size, depending as it does on sensitivity factors of the methods of observation used, will bear no simple relationship to the *actual* size. However, on page 161, we find observed data showing that the apparent size of a comet increases with increasing solar distance given as evidence that a comet's coma is not produced by solar heating. Dr. Lyttleton cannot have his cake and eat it too! This example may serve as a caution to the reader that many of the apparent agreements of prediction with observation naively interpreted may be misleading.

The final chapter examines the relationship between the present theory and earlier ideas of cometary origin. This chapter is far too short, and gives the impression that it was added as an afterthought, without any conviction of its value or necessity on the part of the author, to forestall criticisms of partiality and to justify the title of the book. It hardly fulfils this purpose.

It is true that many of the earlier ideas were the wildest of speculations without any basis in theory or observation, and one can have some sympathy with the author's scathing remarks about them. They lead him, however, to some doubtful polemics on the relationship between theory and observation; thus, because Crommelin was an assiduous student of the observational aspects of comets, the author, when discussing Crommelin's "prominence theory," says "if ever the futility of the direct observational approach to theoretical problems were clearly demonstrated the present suggestion remains a monument." Yet what is a solely theoretical problem?

This attitude on the part of the author prompts him to neglect at least two important recent contributions on the nature of comets that are far from wild speculation. Thus Oort, in his 1951 Halley lecture (*Observatory*, **71**, 129, August 1951) claims observational sanction for the hypothesis of a cloud of comets at a distance of some 10^5 astronomical units from the sun. Lyttleton calls this "another obscurant idea dating back indefinitely," but neither mentions Oort nor attempts to refute his arguments. Again, Whipple (*Astrophys. J.*, **111**, 375, etc.) derives from a far more detailed examination of the observations of comets than has been made in this book, a model for a comet completely at variance with the model here proposed; again, neither mention nor criticism of this work is made.

A detailed critical analysis of theories of the origin and nature of comets would have been most valuable; in this respect *The Comets and their Origin* is disappointing, and furthermore might mislead the unwary into thinking that the accretion theory is the "be all and end all" of cometary theories. However, it is probably true that the accretion theory is the first attempt at a complete unified theory of the origin of comets, and as such is of considerable importance. As a popular account of this theory, and an introduction to the original papers, this book can be thoroughly recommended.

M. W. OVENDEN.

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CORRESPONDENCE

Our Neighbour Worlds

SIR,

As Mr. P. A. Moore rightly assumes, the dimensions of Bailly were given by me after his paper appearing in the January, 1952 issue of *J.B.I.S.*, which is expressly referred to in my book. Since my object was to give a general description of the Moon rather than dwell on the details of its surface, this was not a matter that would normally require discussion by letter. I am, however, glad to learn that the issue is not finally settled.

I may add that Mr. Moore's paper appeared shortly before my MS. went to print, so that the information was as up to date as possible.

Lochearhead, Perthshire. V. A. FIRSOFF.

Planetary Engineering

SIR,

I should like to comment on the "balloon-type inflated buildings" referred to by Mr. Hope-Jones (*J.B.I.S.*, **12** (4), 196), as follows:—

(1) While I do not feel that there would be any real difficulty in constructing air-locks in the side of the dome, the whole problem is obviated by using a subway type of entrance, with locks at the middle underground section, between the stairs or elevators, as Mr. Hope-Jones himself tentatively suggested in his paper.

(2) I agree it would be folly to attempt to fix anything to the walls, as this would introduce additional loadings, for which the dome would not be suitable, and the fabric might be locally overstressed. The internal structures should not connect to the dome at all, and would be of more conventional design.

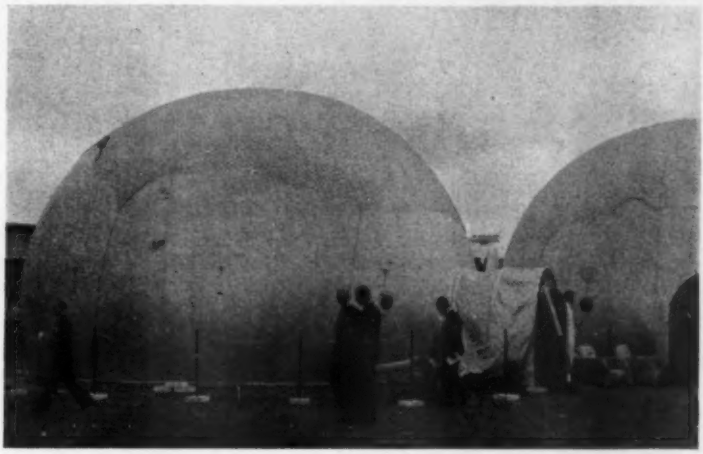
(3) The only strength required of a fabric dome is tensile; which property is possessed by glass fabric to a far greater degree than any orthodox structural material. With a pressurized building in near-vacuum conditions, the loading imposed by air pressure dominates the design. The ordinary rectangular building is the least efficient in combating this, whilst the majority of our normal structural materials are more suited to counter compressive stresses rather than the tensile stresses which occur in the efficient spherical construction. (A complete sphere is theoretically the best, but there are objections to this, and the hemi-spheric dome will more likely be adopted.) It then becomes a choice of sheet steel or glass cloth, and the latter wins on the grounds of lightness and ease of stowage (i.e. in comparison to steel).

(4) The very great problem of temperature effects will occur with all types of structure.

(5) The dome will probably be in two thicknesses of cloth, with a self-sealing compound in between to protect against the risk of punctures. The possibility of large meteors can be neglected, if only on the grounds that no adequate protection could be installed in any case.

P. L. SOWERBY.

West Didsbury, Manchester, 20, Lancs.



Examples of air-inflated structures. Note air-locks on right and compressor unit to maintain internal pressure.

A Note on Centripetal Force

SIR,

I should like to draw attention to the common misconception that a centrifugal force acts on a satellite describing a circular orbit around the Earth.

If we consider the simple two body system formed by the Earth and a satellite, and neglect the gravitational fields of all other bodies, the only forces acting are the mutual gravitational pulls of the two bodies, directed towards their centres of mass.

The satellite and the Earth will describe circular orbits at the same angular velocity around the centre of mass of the system. In practice, an artificial satellite would have a very small mass compared to the Earth, and so the radius of the Earth's orbit about the mass centre would be very small compared to that of the satellite.

It is a fundamental requirement that, for a body to describe a circular path, a force must act upon it directed towards the centre of the circle. This force is known as centripetal force. In the case described above, it is provided by the gravitational pulls of the bodies on one another.

Centrifugal (or outwardly directed) forces, of the type encountered, for example, in rotating machinery, do not occur in the case considered. If a centrifugal force did exist which balanced the gravitational pull, as suggested by many writers, the resultant force on the satellite would be zero, and it would not be able to describe a circular orbit.

Westbury-on-Trym,
Bristol.

S. W. GREENWOOD.

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